Draft <u>Final</u> Report

Non-Aqueous Phase Liquid Focused Feasibility Study for the Soil and Groundwater Operable Units (OU2/OU4) Wyckoff/Eagle Harbor Superfund Site, Bainbridge Island, WA

Prepared for

U.S. EPA, Region 10

<u>October</u> 2015

CH2MHILL®

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Contents

Appendixes

Tables

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Figures

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Acronyms and Abbreviations

%RE	percentage of reference emitter
amsl	above mean sea level
ARARs	applicable or relevant and appropriate requirements
AST	aboveground storage tank
bgs	below ground surface
BTEX	benzene, toluene, ethylbezene, xylenes
~~C~~	~~centigrade~~
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm/s	centimeters per second
COC	contaminant of concern
CSM	conceptual site model
CUL	clean-up level
CY	cubic yard
DAF	dissolved air flotation
DF	dilution factor
DNAPL	dense non-aqueous-phase liquid
DPT	direct push boring
EAB	enhanced aerobic biodegradation
Ecology	Washington State Department of Ecology
ELCR	excess lifetime cancer risk
EC	engineering control
F	Fahrenheit
FFS	focused feasibility study
FPA	Former Process Area
FS	feasibility study
ft	feet
ft^2	square feet
g/cc	grams per cubic centimeter
g/mL	grams per milliliter
GAC	granular activated carbon
gpm	gallons per minute
GRA	general response action
GSI	groundwater – surface water interaction
GWTP	groundwater treatment plant
HPAH	high-molecular weight PAH
IC	institutional control
ISCO	in situ chemical oxidation
ISS	in situ solidification/stabilization

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kW	kilowatt
LIF	laser-induced fluorescence
LNAPL	light non-aqueous -phase liquid
LPAH	low-molecular weight PAH
MCL	maximum contaminant level
mg/L	milligrams per liter
MLLW	mean lower low water
mm	millimeters
MNA	monitored natural attenuation
MTCA	Model Toxics Control Act
MTTD	medium-temperature thermal desorption
MVS	Mining Visualization Software
NAPL	non-aqueous-phase liquid
NCY	NAPL contaminated soil cubic yards
NPDES	National Pollutant Discharge Elimination System
OU	operable unit
O&M	operations and maintenance
PAH	polycyclic aromatic hydrocarbons
psi	pounds per square inch
PCP	pentachlorophenol
ppm	parts per million
PRG	preliminary remediation goal
QAPP	quality assurance project plan
RAO	remedial action objective
RCRA	Resource Conservation ~~Recvoery~~Recovery Act
RI	remedial investigation
ROD	Record of Decision
SVE	soil vapor extraction
SVOC	semivolatile organic compound
TarGOST	Tar-specific Green Optical Scanning Tool
TPH	total petroleum hydrocarbons
TPH-Dx	TPH-diesel
USACE	United States Army Corps of Engineers
USCS	Unified Soil Classification System
USEPA/EPA	United States Environmental Protection Agency
WAC	Washington Administrative Code

Executive Summary

This report presents a ~~non-aqueous phase liquid (NAPL)~~ focused feasibility study (FFS) conducted for the Wyckoff/Eagle Harbor Superfund Site (Wyckoff Site, or Site) Soil and Groundwater Operable Units (OUs). As described in the *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (U.S. Environmental Protection Agency [EPA], 1988), the feasibility study (FS) consists of three phases: screening remedial technologies, developing remedial action alternatives, and conducting a detailed analysis of the alternatives. The scope of the FFS is similar to the FS, however, the FFS addresses a specific problem or portion of a contaminated site. For the Wyckoff Soil and Groundwater OUs, this FFS specifically targets non-aqueous phase liquid (NAPL) present in soil and groundwater underlying the Former Process Area (FPA). ~~Contaminated soil and groundwater that lies outside the NAPL footprint are not addressed.~~

Focused Feasibility Study Approach

Remedial action alternatives were developed for detailed evaluation in this FFS by combining various technologies, and the media to which they are applied, into alternatives that address NAPL source material. The overall FFS approach included the following steps:

- Step 1—Develop remedial action objectives (RAO) specifying the contaminants of concern (COCs) and their corresponding clean-up levels, the environmental media, and the exposure pathways to be addressed. Most information associated with this step, which is discussed in Section~~Chapter~~ 2 of this FFS, was obtained from *Wyckoff Eagle Harbor Superfund Site – OUs 2 and 4 Draft Remedial Action Objective Meeting Minutes* (Snider, 2013) and the *Draft Wyckoff Soil and Groundwater OUs RAOs* (EPA, Revised May 18, 2014).

- Step 2—Identify the areas and volumes (e.g., remedial action target area or target zones) of contaminated media to be addressed. This is a key element that is summarized in Section~~Chapter~~ 2 of this FFS. The remedial action target area was identified as described in the *Groundwater Conceptual Site Model Update Report for the Former Process Area, Wyckoff/Eagle Harbor Superfund Site, Soil and Groundwater Operable Units* (Draft CSM Update Report; CH2M HILL, 2013a).

- Step 3—Identify general response actions (GRA) for environmental media to be addressed, individually or in combination, which may be taken to achieve the RAOs. GRA categories applicable to NAPL present in the FPA include: no action, access controls, containment, removal and disposal, ex situ treatment, and in situ treatment.

- Step 4—Identify and screen the technologies and their associated process options applicable to each GRA to eliminate those that are not viable for NAPL and the subsurface conditions present in the FPA. The screening process includes an evaluation of each technology based on considerations of effectiveness, implementability, and relative cost. The technology screening, which is presented in Section~~Chapter~~ 2 of this FFS, was performed as generally described in *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, Interim Final* (EPA, 1988).

- Step 5—Assemble the retained technologies into a range of source control alternatives in accordance with the National Contingency Plan (NCP; Code of Federal Regulations [CFR], Title 40, Section 300.430(e)(3). When assembling alternatives containing multiple technologies, consideration was given to those that are compatible and complementary. The results from this step are presented in Section~~Chapter~~ 3 of this FFS.

- Step 6—Conduct a detailed and comparative analysis of the alternatives individually, and relative to one another, against the evaluation criteria specified in the NCP, 40 CFR 300.430(e)(9). The detailed evaluation of the alternatives against the criteria of state acceptance and community acceptance was not performed in this FFS but will be conducted as described in the NCP, 40 CFR 300.430(e)(9)(iii)(H) and (I). The results from this step are presented in Section~~Chapter~~ 4 of this FFS.
- Step 7—Identify a recommended alternative. Based on the results of the detailed and comparative evaluation and discussions between EPA, Washington State Department of Ecology (Ecology) and community representatives, a recommended alternative was identified as summarized in Section~~Chapter~~ 5 of this FFS. The recommended alternative will be identified as the Preferred Alternative in the Proposed Plan.

As shown on Exhibit ES-1, The FFS/FS represents Step 2 of the decision process that leads to selecting a remedy for a Superfund site. Following EPA and Ecology review of this draft FFS, EPA, as the lead regulatory agency, will prepare and issue a Proposed Plan that will undergo public review and participation in accordance with 40 CFR 300.430(f). Following receipt of public comments and preparation of a Responsiveness Summary that address public comments, EPA will issue a Comprehensive Environmental Response Compensation and Liability Act (CERCLA) decision document that selects a remedial action alternative to address NAPL source material present in the Wyckoff Soil and Groundwater OUs.

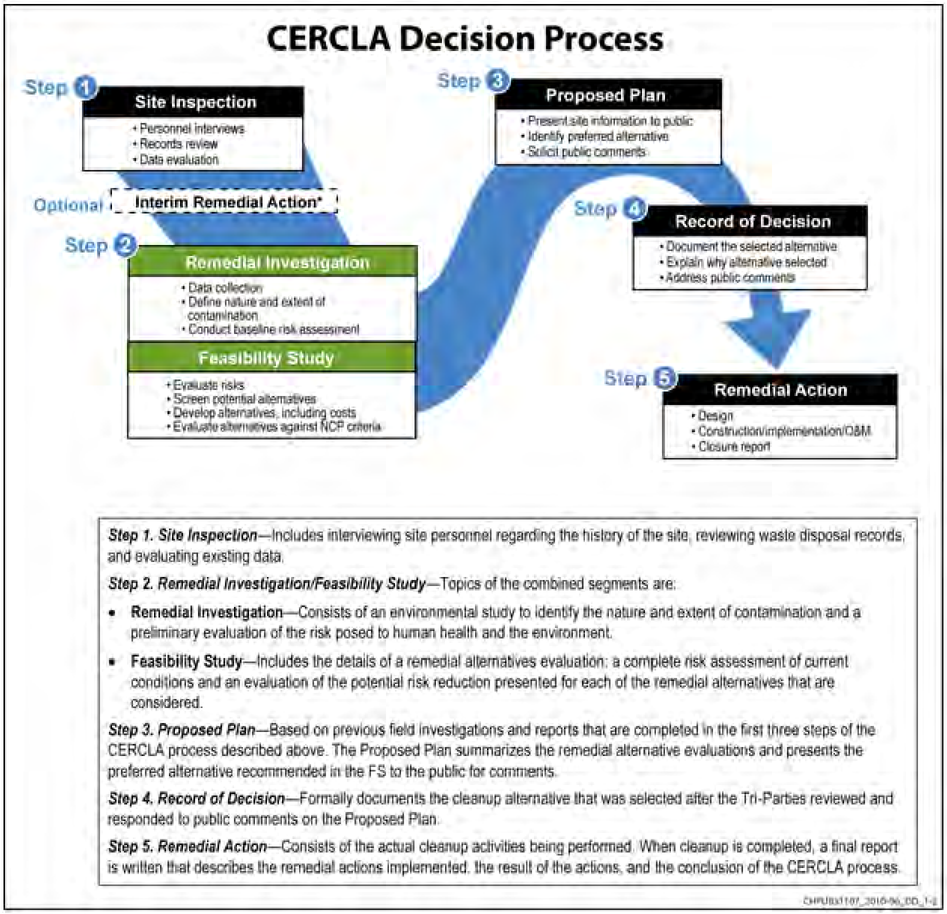

EXHIBIT ES-1
Comprehensive Environmental Response Compensation and Liability Act Decision Process

Remedial Action Target Area

The area and volume of NAPL-contaminated source material to be addressed in the FFS was defined using information obtained from a Tar-~~s~~Specific Green Optical Scanning Tool (TarGOST®) field investigation conducted in 2013. The objective for the TarGOST investigation was to define the distribution of NAPL within the Upper Aquifer underlying the FPA. Based on evaluation of the field investigation results (*2014 Conceptual Site Model Update for the OU2 and OU4 Former Process Area*, CH2M HILL, 2014) a TarGOST response of 10 percent reference emitter (%RE) was identified as signifying the presence of NAPL. Because the TarGOST measurements do not specifically indicate the presence of mobile or immobile (residual) NAPL, all locations and depths with a TarGOST response of 10 %RE or greater were identified as NAPL source material. The volume of NAPL contaminated aquifer material (in

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cubic yards), and the volume of NAPL present (in gallons), lying within the 10% RE TarGOST footprint ~~was~~were then estimated using information obtained from each of the 141 TarGOST borings drilled in the FPA and by converting the TarGOST measurements into a NAPL concentration.

The TarGOST results were used to define the following five remedial action target zones that are described in this FFS: (1) the Core Area and an Expanded Core Area, (2) North Shallow (Light NAPL [LNAPL]) area, (3) East Shallow (LNAPL) area, (4) North Deep (Dense NAPL [DNAPL]) area, and (5) the Other Periphery area. ~~Based on evaluation of the TarGOST data, 99 percent of the Upper Aquifer underlying the FPA by soil volume was identified for remedial action.~~

Remedial Action Alternatives

The technologies retained from the screening performed in Step 4 were assembled into a range of source control alternatives in accordance with the NCP under 40 CFR 300.430(e)(3). Technology and technology combinations identified for each target zone included the following:

- **Core Area/Expanded Core Area:** Containment, In Situ Solidification/Stabilization (ISS), Excavation and Thermal Desorption, Thermal Enhanced Extraction, ~~Enhanced Recovery,~~ and Enhanced Aerobic Biodegradation (EAB)
- **North Shallow (LNAPL):** Containment, ISS, Excavation and Thermal Desorption, Thermal Enhanced Extraction, Thermal Enhanced Recovery, and EAB
- **East Shallow (LNAPL):** Containment, ISS, Excavation and Thermal Desorption, Thermal Enhanced Extraction, Thermal Enhanced Recovery, NAPL Recovery, and EAB
- **North Deep (DNAPL):** Containment, ISS, Thermal Enhanced Extraction, Thermal Enhanced Recovery, NAPL Recovery, and EAB
- **Other Periphery:** Containment, ISS, Thermal Enhanced Extraction, Thermal Enhanced Recovery, and EAB

NAPL Recovery was often paired with Thermal Enhanced Recovery and Thermal Enhanced Extraction because it is a complimentary technology that can increase the effectiveness and shorten the treatment timeframe required for enhanced methods. EAB is used as a "polishing" technology for deployment in areas with sparse NAPL occurrences and/or for implementation in target zones following completion of more aggressive remedial action.

Based on CERCLA program expectations, a range of seven source control alternatives were assembled. In addition to the technologies named in each alternative title, an array of common elements is also required to fully implement each alternative. The seven alternatives include the following:

- **Alternative 1: No Action—**The No Action Alternative was developed per NCP requirements.
- **Alternative 2: Containment—**This is the current remedy implemented under the existing Soil and Groundwater OUs Record of Decision (EPA, 2000).
- **Alternative 3: Excavation, Thermal Desorption, and ISS—**The excavation and thermal desorption components of this alternative would be implemented in the Core Area, North Shallow (LNAPL), East Shallow (LNAPL), and Other Periphery target zone~~s~~, and ISS in the North Deep (DNAPL) target zone.
- **Alternative 4: ISS—**This technology would be implemented in each target zone.

- **Alternative 5: Thermal Enhanced Extraction and ISS—**Thermal enhanced extraction would be implemented in the Core Area, North Shallow (LNAPL), and East Shallow (LNAPL), with ISS implemented in the North Deep (DNAPL) and EAB in the Other Periphery target zones.
- **Alternative 6: Excavation, Thermal Desorption, and Thermal Enhanced Extraction—**The excavation and thermal desorption components of this alternative would be implemented in the Upper Core Area with thermal enhanced extraction implemented in the Lower Core Area, North Deep (DNAPL), North Shallow (LNAPL), and East Shallow (LNAPL) areas, and EAB in the Other Periphery target zone.
- **Alternative 7: ISS of Expanded Core Area and Thermal Enhanced Recovery—**ISS would be implemented in an expanded Core Area during the initial remedy implementation phase (Phase 1) with thermal enhanced recovery implemented in the remaining target zones outside the ISS footprint during a subsequent phase (Phase 2). This alternative also includes: NAPL recovery in the North Deep (DNAPL) and East Shallow (LNAPL) target areas, and EAB in the Other Periphery area.

Following development, the seven alternatives identified above were screened against the NCP criteria of effectiveness, implementability, and cost as described in 40 CFR 300.430(e)(7). Based on the results of this screening, Alternative 3 – Excavation, Thermal Desorption, and Thermal Enhanced Extraction was eliminated based on implementability considerations. The shoring and dewatering necessary to implement the deep excavation technology at the Site under Alternative 3 was determined to pose significant geotechnical risk.

Detailed Evaluation of Alternatives

The six remedial action alternatives (~~e.g.~~ Alternatives 1, 2, and 4 through 7) retained following the initial screening were carried forward for more detailed engineering development and evaluation against the CERCLA threshold and balancing criteria described in the NCP under 40 CFR 300.430(e)(9). The alternatives will be evaluated against the modifying criteria during the CERCLA public participation process that occurs following issuance of the Proposed Plan.

In addition to the individual evaluation of each alternative against the CERCLA criteria, which is presented in Section~~Chapter~~ 4 of this FFS, the alternatives were evaluated relative to one another to identify key trades-offs. The comparative evaluation (see Table ES-1) was used to facilitate a ranking of the alternatives and identification of a recommended alternative. During preparation of the Proposed Plan, EPA will identify a preferred alternative that may differ from the recommended alternative identified in this FFS. ~~Based on the results of the detailed and comparative evaluation, Alternative 4—In Situ Stabilization/Solidification, and Alternative 5—Thermal Enhanced Extraction and ISS, were ranked comparably.~~

Recommended Alternative

To be provided~~Due to a shorter estimated timeframe to achieve RAOs (see Exhibit ES-2), and a lower level of long-term Site management, Alternative 4 was initially identified during stakeholder discussions as the recommended alternative. The estimated timeframe to achieve RAOs shown on Exhibit ES-2 assumes an aggressive – continuous implementation schedule with no technical, regulatory, or financial uncertainties.~~

~~Further, EPA and Ecology discussions are planned, and a presentation to the National Remedy Review Board may result in a different recommended alternative or identification of new technology combinations and new alternatives. Selection of the final alternative will occur in a CERCLA decision document following completion of the public participation process~~.

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TABLE ES-1
Comparative Evaluation of Alternatives
Soil and Groundwater OUs – Former Process Area
Wyckoff/Eagle Harbor Superfund Site, Bainbridge Island, Washington

Criterion	Alternative 1 – No Action	Alternative 2 - Containment	Alternative 4 - ISS	Alternative 5 – Thermal Enhanced Extraction and ISS	Alternative 6 – Excavation, Thermal Desorption, and Thermal Enhanced Extraction	Alternative 7 – ISS of Expanded Core Area and Thermal Enhanced Recovery
Key Treatment Technologies						
- Core Area	Natural attenuation	Soil cap, hydraulic containment, and ICs	ISS, soil cap	Enhanced NAPL recovery, thermal enhanced extraction, EAB	Upper Core - Excavation, thermal desorption Lower Core – Enhanced NAPL recovery, thermal enhanced extraction, EAB	ISS
- East Shallow (LNAPL)					Enhanced NAPL recovery, thermal enhanced extraction, EAB	NAPL recovery, thermal enhanced recovery, EAB
- North Shallow (LNAPL)						
- North Deep (DNAPL)				ISS		
- Other Periphery				EAB	EAB	EAB
Percent of NAPL Treated using Key Technologies						
– Hydraulic Containment	--	?	--	--	--	--
– NAPL Recovery	--	?	--	--	--	--
– ISS	--	--	?	?	--	37
– Enhanced NAPL Recovery/Thermal/EAB	--	--	--	?/?/? (? total)	?/?/? (? total)	?/?/? (? total)
– Excavation	--	--	--	--	14	--
– Passive Groundwater Treatment	--	--	1	1	1	1
– Natural Attenuation	100	Not Determined	Not Determined	Not Determined	Not Determined	Not Determined
Threshold Criteria						
Protects HHE	No	Yes	Yes	Yes	Yes	Yes
Complies with ARARs	No	Yes	Yes	Yes	Yes	Yes
Balancing Criteria						
Long-term Effectiveness and Permanence	Not evaluated	★☆☆	★★★	★★★	★★★	★★★
Reduction of TMV through Treatment	Not evaluated	★☆☆	★★★	★★★	★★★	★★★
Short-term Effectiveness		★★☆ O&M limited to 100 years	★★☆	★★☆	★★☆	★★☆
Implementability		★★☆	★★☆	★☆☆	★☆☆	★★☆
Cost (millions) – Total Present Worth Cost – 1.4% discount – Total Present Worth Cost – 7% discount – Total Non-discounted Cost	 $0 $0 $0	 $79.8 $52.0 $111.0	 $93.7 $88.6 $95.4	 $142.6 $120.1 $149.6	 $197.7 $161.5 $210.0	 $110.6 $80.9 $121.8
Modifying Criteria						
State Acceptance	Not evaluated in this FFS					
Community Acceptance						

★★★ = The alternative performs very well against the CERCLA balancing criterion with minimal disadvantages or uncertainties

★★☆ = The alternative performs moderately well against the CERCLA balancing criterion but with some disadvantages or uncertainties

★☆☆ = The alternative performs less well against the CERCLA balancing criterion with more disadvantages or uncertainty

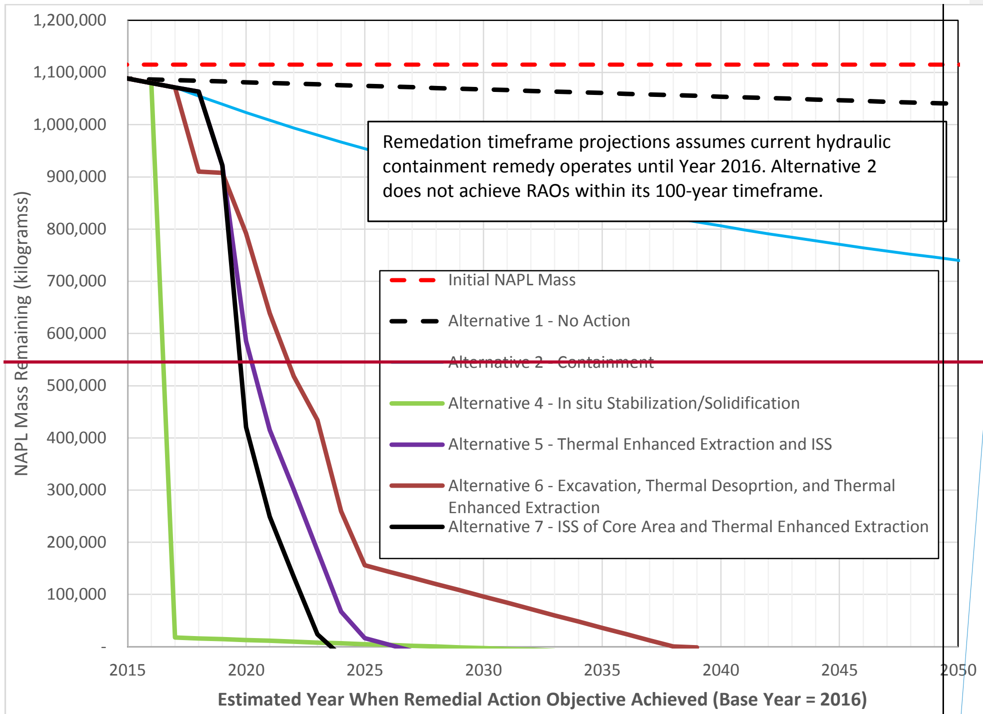

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EXHIBIT ES-2

Remedial Action Alternative Technology Durations~~Estimated Timeframe to Achieve Remedial Action Objectives~~

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Alt 7 – Thermal Enhanced Recovery

SECTION 1

1 Introduction

This report presents the draft Focused Feasibility Study (FFS) conducted for the Wyckoff/Eagle Harbor Superfund Site (Wyckoff Site, or Site) Soil and Groundwater Operable Units (OUs) located on Bainbridge Island, Washington. The FFS describes the process by which remedial action alternatives were developed and evaluated to assist in identifying a recommended alternative to address non-aqueous-phase liquid (NAPL) source material underlying the Site's Former Process Area (FPA). This FFS was prepared as one of the work scope items included under Task Order 079-RI-FS-10S1 of the U.S. Environmental Protection Agency (EPA) Region 10 and CH2M HILL Architecture and Engineering Services Contract No. 68-S7-04-01.

1.1 Purpose and Report Organization

A feasibility study (FS) ensures that appropriate remedial action alternatives are developed and evaluated so that relevant information concerning the remedial action options can be presented and an appropriate remedy selected. This document is referred to as an FFS, rather than an FS, because it addresses a specific problem within the Soil and Groundwater OUs; that is NAPL source material.

As described in *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA, 1988), the FFS/FS consists of three phases:

- Screening remedial technologies
- Developing remedial action alternatives
- Conducting a detailed analysis of the alternatives

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The results of the first two phases were presented in the *Wyckoff/Eagle Harbor Soil and Groundwater Operable Units Focused Feasibility Study - Remedial Technology Screening and Preliminary Remedial Action Alternatives* (CH2M HILL, 2014). Much of the information presented in the February 2014 Technical Memorandum is included herein for completeness to support the identification of a recommended alternative in this draft FFS report.

The content and format of this document is based on the suggested FS report format described in *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA, 1988) as follows:

- Section 1 – Introduction
- Section 2 – Identification and Screening of Technologies
- Section 3 – Development and Screening of Alternatives
- Section 4 – Detailed Analysis of Alternatives
- Section 5 – Recommended Alternative
- Section 6 - References

The tables and figures called out in this document are presented in separate sections that follow Section 6. This FFS report also contains several key appendices that provide important contributing information as follows:

- **Appendix A, Soil and Groundwater Operable Units Applicable or Relevant and Appropriate Requirements,** contains an evaluation of applicable or relevant and appropriate requirements (ARARs) that specify federal and ~~state~~ State of Washington regulations that govern the soil and groundwater clean-up levels that need to be achieved by the NAPL source area remedial action, and the manner in which the remedial action alternatives are to be implemented.
- **Appendix B, Remedial Action Alternative Drawings,** contains the engineering drawings that illustrate conceptual level design information for the common elements and remedial action alternatives described in ~~Chapter~~Section 3.
- **Appendix C, ~~Common Element and~~ Remedial Action Alternative Cost Estimate,** contains a -30/+50 percent cost estimate for each remedial action alternative carried forward for the detailed analysis of alternatives presented in ~~Chapter~~Section 4.
- **Appendix D~~, Remedial Action Alternative Timeframe Projections,~~** ~~summarizes the assumptions and methods that were used to estimate the time required to achieve remedial action objectives (RAOs) for each of the remedial action alternatives carried forward for the detailed analysis of alternatives presented in ChapterSection 4. *(Note: This appendix is still being prepared and will be included with the next submittal.)*~~
- **~~Appendix E~~, Wyckoff NAPL Composition**, presents laboratory analysis results from testing of NAPL samples collected at the Site.

1.2 Background Information

This section summarizes background information for the Wyckoff/Eagle Harbor Superfund Site Soil and Groundwater OUs, including the Site description, Site history investigation chronology, nature and extent of NAPL contamination, baseline risk, and status of the ongoing containment remedy. Most information was adapted from the following:

- *EPA Superfund Record of Decision: Wyckoff Co./Eagle Harbor, EPA ID: WAD009248295, OU 02, 04, Bainbridge Island, WA* (2000 ROD; EPA, 2000)
- *Groundwater Conceptual Site Model Update Report for the Former Process Area Wyckoff/Eagle Harbor Superfund Site, Soil and Groundwater Operable Units* (CH2M HILL, 2013a)

1.2.1 Site Description

The Wyckoff/Eagle Harbor Superfund Site is located on the east side of Bainbridge Island, Kitsap County, Washington (**Figure 1-1**). The Site was divided into the following four OUs based on environmental media, contaminant sources, and environmental risks:

- **OU1** or the **East Harbor OU** (subtidal/intertidal sediments in Eagle Harbor contaminated by polycyclic aromatic hydrocarbons [PAHs])
- **OU2** or the **Wyckoff Soil OU** (unsaturated soil contaminated with PAHs and pentachlorophenol [PCP])
- **OU3** or the **West Harbor OU** (subtidal/intertidal sediments in Eagle Harbor contaminated by metals, primarily mercury, and upland sources)
- **OU4** or the **Wyckoff Groundwater OU** (the saturated soil and groundwater beneath OU2)

The Wyckoff Site spans approximately 57 acres of which OU2 and OU4 occupy about 18 acres. OU2/OU4 comprises the following three geographic areas: FPA, Former Log Storage/Peeler Area, and the Well

CW01 Area. This FFS only addresses those portions of OU2/OU4 lying beneath the approximate 8-acre FPA, where most NAPL occurs. The Log Storage/Peeler Area and the Well CW01 Area are not discussed is this FFS report; additionally, OU1 and OU3 are also not discussed. OU1 is addressed in a separate FFS, while OU3 was addressed in a previous Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) decision document, *EPA Superfund Record of Decision Amendment: Wyckoff Co./Eagle Harbor EPA ID: WAD009248295 OU 03 Bainbridge Island, WA, EPA/AMD/R10-96/131* (EPA, 1996).

1.2.1.1 Hydrogeology

This section summarizes the hydrogeology underlying the FPA. This includes information on the key hydrostratigraphic units, groundwater flow patterns, and groundwater/surface water interaction (GSI). This hydrogeologic understanding is based on the cumulative findings of numerous investigations (**Table 1-1**) that included drilling soil borings (geotechnical, direct push, probes, and/or cone penetrometer) and installing monitoring wells, piezometers, and/or extraction wells. Currently, there are 77 wells present in the FPA (**Figure 1-2**).

Based on geologic logging of the soil and well boreholes, the deepest of which is 127 feet below ground surface (bgs), there are four primary hydrostratigraphic units: Vadose Zone, Upper Aquifer, Aquitard, and the Lower Aquifer. A geologic cross-section showing the key hydrostratigraphic units is shown on **Figures 1-2** and **1-3.**

Vadose Zone

The vadose zone, or unsaturated zone above the water table, generally consists of fill material that extends from ground surface to depths ranging from 6 feet in the west portion of the FPA to 13 feet in the northeast portion. The vadose zone thickness varies with seasonal and tidally influenced groundwater elevations. Within the vadose zone, buried infrastructure, debris, and building foundations occurs within the footprint of the FPA (**Figure 1-4**). Some of these features are exposed at the ground surface, whereas others have been covered during filling and regrading activities. Buried debris is an important consideration for the FFS, because unless removed, it may affect NAPL source area remedy implementation.

Direct contact with the NAPL-contaminated soil present in the vadose zone, and associated with buried debris, represents the primary human health exposure pathway in the Soil and Groundwater OUs. Leaching of contaminants from NAPL present in vadose zone soil or associated with buried debris also represents a groundwater contaminant source.

Upper Aquifer

The Upper Aquifer consists primarily of sand and gravel with groundwater occurring under unconfined or water table conditions. Groundwater elevations range from about 7.5 to 10 feet mean lower low water (MLLW) under nonpumping, seasonal low conditions (based on September 2012 data). Daily tidal fluctuations have significantly influenced Upper Aquifer groundwater elevations, especially along the shoreline. These variations can result in water table fluctuations ranging from 1 to 10 feet. After the perimeter sheet pile wall was installed in 2001, tidal influence has diminished, and most wells now show a tidal influence ranging from 0.1 to 4 feet.

The perimeter or outer sheet pile wall bounding the north and east ends of the FPA is an important feature, because it represents an Upper Aquifer groundwater flow barrier. The ~~integrity of the~~ sheet pile wall influences the Upper Aquifer's hydraulic response to seasonal water level changes and daily Puget Sound-Eagle Harbor tidal cycles. The s~~S~~heet pile wall ~~integrity~~ also controls ~~affects~~ soil, NAPL and dissolved-phase contaminant transport from the Soil and Groundwater OUs to the East Harbor (OU1) and West Harbor (OU3) OUs.

~~The sheet pile wall integrity evaluation presented in the *Wyckoff Sheet Pile Wall – Non-Aqueous Phase Liquid and Plume Migration Barrier Effectiveness Evaluation* (CH2M HILL, 2013b) concluded that, while there is some hydraulic seepage though the sheet pile wall via the individual pile joints, comparing current to historical Upper Aquifer tidal efficiency factors, combined with the understanding of sheet pile wall schematics, indicates that the total groundwater flux through the sheet pile wall is significantly less than prewall conditions. Field observations made at the five channels welded to the sheet pile wall seams suggest that NAPL migration through the seams is possible; however, if it is occurring, the flux would be significantly less than prewall conditions.~~

As shown on **Figure 1-3**, groundwater flow in the Upper Aquifer before the sheet pile wall was installed (original conditions) was from the inland area towards Eagle Harbor and Puget Sound, where it discharged to the intertidal and subtidal zones. Groundwater flow patterns in the Upper Aquifer are currently influenced by the perimeter sheet pile wall and hydraulic containment pumping, which generally promote an inward groundwater flow pattern.

Per the 2000 ROD (EPA, 2000), due to elevated salinity, Upper Aquifer groundwater beneath the FPA is not currently extracted, nor is it expected to be extracted in the future, for potable, agricultural, or industrial purposes. Elevated salinity is a natural condition that results from saltwater intrusion attributed to tidal cycles and the Site's proximity to Puget Sound/Eagle Harbor. The EPA and Washington State Department of Ecology (Ecology) have determined that Upper Aquifer groundwater in the FPA is nonpotable because it is affected by salinity. The assignment of a nonpotable, Class III groundwater beneficial use designation (total dissolved solids greater than 10,000 milligrams per liter [mg/L]) to Upper Aquifer groundwater present beneath the FPA is consistent with EPA's *Guidelines for Ground-Water Classification Under the EPA Ground-Water Protection Strategy* (EPA, 1986) and Washington Administrative Code (WAC) 173-340-720(2)(a)(ii).

Aquitard

The Aquitard is a dense layer of marine silt, glacial deposits, and nonmarine clay material that separates the Upper Aquifer from the Lower Aquifer. The top of the Aquitard, which dips northeast, extends from near ground surface in the south-central portion of the Wyckoff Site to approximately 90 feet bgs along the northern portion. Based on numerous field explorations conducted during the Soil and Groundwater OUs remedial investigation (CH2M HILL, 1997), and various United States Army Corps of Engineers (USACE) exploratory drilling events (USACE, January 1998, April 1998, May 2000, October 2006), the Aquitard appears continuous throughout most of the FPA.

The Aquitard's thickness ranges from 10 to 40 feet, with the thinnest areas located near the northeast corner and central portion of the FPA. Borings drilled along the south hillside in 2004 to characterize the area for an upgradient cutoff wall (CH2M HILL, 2004) identified localized areas where the Aquitard was not visibly evident in the far southwest and southeast corners of the Site.

Lower Aquifer

The Lower Aquifer consists primarily of sand, with small amounts of silt, clay, and gravel. While the thickness and depth to the bottom of the Lower Aquifer have not been determined at the Site, it is believed that it extends to a depth of approximately 200 or 250 feet bgs. This estimate is based on the regional work of Frans et al. (2011) and the logs recorded for two deep, on-Site water supply wells that were decommissioned in 1997 and for a new water supply well that was completed in January 2002.

The direction of groundwater flow in the Lower Aquifer is also from the inland area towards Eagle Harbor and Puget Sound, which is a regional groundwater discharge zone, a condition that promotes an upward vertical hydraulic gradient from the Lower Aquifer to the Upper Aquifer. The sheet pile wall and Upper Aquifer hydraulic containment pumping do not influence horizontal groundwater flow patterns in the Lower Aquifer.

Per the 2000 ROD, groundwater in the Lower Aquifer (approximately 80 to 200 feet bgs) is considered potable (Class II B, Groundwater Not a Current Source but Potential Future Source), although this aquifer has never been used for drinking water at the Site. Routine groundwater monitoring performed in the Lower Aquifer has measured salinity levels that exceed the upper-bound potable water total dissolved solids concentration of 10,000 mg/L (EPA, 1986; WAC 173-340-720[2]) at locations up to 200 feet inland of the outer sheet pile wall (**Figure 1-5**). If a water supply well were installed in the Lower Aquifer within the FPA and routinely pumped, then the saltwater-freshwater interface would shift further inland. Rising sea levels would also push the freshwater-saltwater interface further inland. Therefore, for this FFS, all Lower Aquifer groundwater within 200 feet of the outer sheet pile wall is deemed Class III due to existing or future levels of elevated salinity.

1.2.2 Site History

From the early 1900s through 1988, a succession of companies treated wood at the Wyckoff property for use as railroad ties and trestles, telephone poles, pilings, docks, and piers. The wood-preserving plant was one of largest in the United States, and its products were sold throughout the nation and the rest of the world. Wood-preserving operations included the following activities: (1) using and storing creosote, pentachlorophenol (PCP), solvents, gasoline, antifreeze, fuel and waste oil, and lubricants; (2) managing process wastes; (3) treating and discharging wastewater; and (4) storing treated wood and wood products.

The main features of the wood-treating operation included a process area that included numerous storage tanks and process vessels such as retorts; a log storage and log peeler area; and a treated log storage area.

There is little historical information about the waste management practices at the Wyckoff facility. Before the Wyckoff facility was reconstructed in the 1920s, logs were reportedly floated in and out of a lagoon that once existed at the Site; the lagoon has since been filled. Treated logs were also transported to and from the facility at the former West Dock via a transfer table pit, and the chemical solution that drained from the retorts after a treating cycle went directly on the ground and seeped into the soil and groundwater below the surface. This practice began around the mid-1940s until operations ceased in 1988. Wastewater was also discharged into Eagle Harbor for many years, and the practice of storing treated pilings and timber in the water continued until the late 1940s. The log storage area was primarily used to store untreated wood. **Table 1-1** summarizes a chronology of key investigation, enforcement, and clean-up activities conducted for the Soil and Groundwater OUs.

1.2.3 Nature and Extent of Contamination

This section summarizes NAPL distribution in the Soil and Groundwater OUs underlying the FPA. The three-dimensional NAPL contamination footprint defines the area where remedial action is proposed in this FFS.

1.2.3.1 Upper Aquifer

The distribution of NAPL in the Upper Aquifer was defined using the results of Tar-s~~S~~pecific Green Optical Scanning Technology (TarGOST) investigations conducted in 2012 and 2013 as described in the *2013 Wyckoff Upland NAPL Field Investigation Technical Memorandum Field Summary Report*

(CH2M HILL, 2013c). During the 2013 upland NAPL field investigation, 141 primary and 7 replicate TarGOST borings (**Figure 1-6**) and 20 confirmation direct-push technology (DPT) soil borings were advanced to characterize the horizontal and vertical distribution of NAPL in the Upper Aquifer.

The TarGOST technology does not explicitly measure an absolute NAPL saturation; instead, it measures the "optically available" NAPL that passes against the small window in the probe as it advances downward in the subsurface. A laser is emitted through the window, and the florescent response of the NAPL is captured and transmitted by fiber optics to a detector on the surface. A standard "reference emitter" (e.g., an oil with a known florescent response) is used to calibrate the instrument daily, and the individual readings are given as a percentage of the reference emitter (%RE).

The results were interpreted to select a TarGOST response factor that marks the transition from NAPL absent to NAPL present. Based on evaluation of the TarGOST data (CH2M HILL, 2013c) a TarGOST response factor of between 5%RE and 10%RE was selected as signifying NAPL presence. Therefore, for this FFS, a TarGOST response of 10%RE and greater was inferred to indicate that NAPL is present. The area enclosed by the 10% RE is shown on **Figure 1-6**.

The findings of the TarGOST investigation revealed the following:

- In general, the aggregate NAPL thickness ~~OF NAPL~~ (~~e.g.~~ i.e., the summed or total thickness of all discrete NAPL layers) is greatest in the center portion ~~core~~ of the FPA (the core area) where the highest TarGOST responses were observed. Extending outward from this core area, the aggregate NAPL thickness and inferred NAPL saturations decrease.
- Outside of the core area, discrete NAPL lenses are vertically distributed but not in an obvious pattern. This distribution likely results from multiple sources, preferential NAPL transport pathways associated with interbedded geologic materials, interaction with variable fluid densities resulting from the Upper Aquifer's transition from freshwater to saltwater, and operation of the Upper Aquifer containment remedy.
- TarGOST responses greater than 10%RE appear to terminate at or above the boring refusal depth, which generally occurs at the top of the Aquitard. In general, where collocated geologic information is available, the TarGOST boring refusal depth is coincident with or slightly below the transition from the Upper Aquifer to the Aquitard's glacial till layer. This indicates that the glacial till is restricting, but not necessarily preventing, NAPL migration to lower depths.
- Along the FPA's east and north sides, elevated TarGOST readings were observed next to the outer sheet pile wall at depths above the Aquitard's glacial till layer. In these areas, the sheet pile wall driven depths are greater than the deepest elevated TarGOST responses.

Because the TarGOST technology provides a relative indicator of NAPL saturation, confirmation soil borings were drilled and visually logged for soil type and NAPL absence and/or presence. The resulting field logs were compiled to evaluate NAPL association with soil type (**Figure 1-7**). Of the nearly 600 feet of soil core recovered, NAPL was observed in 119 feet, or 20 percent of the sampled material. When comparing NAPL occurrences by geologic material, NAPL tends to preferentially inhabit coarser-grained soil. Eighty-two percent of the NAPL present in the soil cores was detected in coarser-grained material consisting of marine sand or marine sand and gravel, and 15.5 percent of NAPL was observed in finer-grained material consisting of marine silt or marine sediment.

To estimate the total volume of NAPL-contaminated material underlying the FPA, TarGOST response data were coupled with a Thiessen polygon analysis where each boring was assigned a representative area based on proximity to adjacent borings and the FPA boundary. Detailed information on the overall approach used to estimate the volume of NAPL-contaminated material is presented in *Groundwater*

Conceptual Site Model Update Report for the Former Process Area Wyckoff/Eagle Harbor Superfund Site, Soil and Groundwater Operable Units (CH2M HILL, 2013a).

Based on interpretation of the TarGOST results, and knowledge of wood-treating formulations, there are distinct hydrogeologic intervals where NAPL occurs as: 1) LNAPL that has spread horizontally and smeared across a tidal and seasonally variable water table surface, and 2) DNAPL that has migrated vertically downward and spread laterally across lenses of fine-grained sediment present within the Upper Aquifer and across the Aquitard's upper boundary. Based on this distribution, the Upper Aquifer was segregated into three vertical compartments (**Figure 1-7**) as follows:

- Compartment 1 – Extends from the ground surface an elevation of +20 feet mean lower-low water (ft-MLLW) to -5 ft-MLLW or 5 ft below the water table.
- Compartment 2 – Extends from an elevation of -5 ft-MLLW to elevations ranging from -20 to -40 ft-MLLW or 10 feet above the top of the aquitard. The variable depth of Compartment 2's bottom reflects the aquitard's northeast dip.
- Compartment 3 – Extends from an elevation ranging from -20 to -40 ft-MLLW to elevations ranging from -20 to -60 ft-MLLW or 10 feet above the Aquitard to the TarGOST boring refusal depth, which is generally at or just below the top of the Aquitard.

The total volume of NAPL-contaminated material present in the Upper Aquifer is estimated at 109,000 cubic yards (CY), or 15 percent of the total soil volume; this translates into a NAPL volume of 679,000 gallons with 302,000 gallons (44 percent) estimated to be present in Compartment 1, 128,000 gallons (19 percent) present in Compartment 2, and 249,000 gallons (37 percent) present in Compartment 3.

Based on the observed geographic distribution of NAPL, the Upper Aquifer remedial action target area was partitioned into a Core Area, where thick sequences of NAPL occur, and a Periphery Area, where thinner lenses of NAPL are present. While evaluating TarGOST information for the Periphery Area, it became apparent that NAPL occurrences in the Periphery Area warranted further subdivision based on considerations of NAPL architecture, geology, depth, and potential remedial technology application. Therefore, the Periphery Area was further partitioned into the following four different target zones: East Shallow (Light NAPL [LNAPL]), North Deep (Dense NAPL [DNAPL]), North Shallow (LNAPL), and Other Periphery. The locations of the five NAPL remedial action target zones are shown on **Figure 1-9,** and the volume of NAPL-contaminated material and estimated volume of NAPL present shown in **Table 1-2**.

The five remedial action target zones are described as follows:

- The **Core Area** is characterized by thick lenses of NAPL that in aggregate account for 44~~36~~ percent ~~most~~ of the NAPL quantity~~contaminated soil volume~~ present in the Upper Aquifer~~mass present in the FPA~~. The volume of NAPL-contaminated soil is estimated at 39~~8~~,0~~7~~00 ~~NAPL CY (N~~CY~~)~~, and this volume is estimated to contain 302,000 gallons of ~~creosote~~NAPL~~, or 7.8 gallons per NCY~~.
- The **East Shallow (LNAPL) Periphery** target zone is located along the east side of the FPA and is characterized by LNAPL present in Compartment 1 and sporadic DNAPL present in Compartment 2 and Compartment 3 that in aggregate account for 31~~40~~ percent of the NAPL quantity ~~contaminated soil volume~~ present in the Upper Aquifer. The volume of NAPL-contaminated soil is estimated at 43,0~~2~~00 CY and this volume is estimated to contain 208,000 gallons of NAPL~~ or 4.8 gallons per CY of NAPL-contaminated soil~~.
- The **North Deep (DNAPL) Periphery** target zone is located on the north end of the FPA. This zone is - characterized by DNAPL present in Compartment 3 but also contains significant NAPL

~~volumes~~ in Compartments 1 and 2 ~~(Upper Aquifer-Aquitard interface)~~. This area contains 13 percent of the NAPL q~~c~~uantity~~ontaminated soil volume~~ present in the Upper Aquifer. The volume of NAPL-contaminated soil is estimated at 14,0~~3~~00 CY and this volume is estimated to contain 87,000 gallons of NAPL ~~or 6.1 gallons per CY of NAPL-contaminated soil~~.

- The **North Shallow (LNAPL) Periphery** target zone is located on the north end of the FPA and is characterized by LNAPL present in Compartment 1 (capillary fringe). It's estimated this area contains 4 percent of the NAPL present in the Upper Aquifer or ~~The volume of NAPL-contaminated soil is estimated at 54,000700 CY and this volume is estimated to contain~~ 30~~29~~,0~~7~~00 gallons ~~of NAPL or 6.3 gallons per CY of NAPL-contaminated soil~~.

- The **Other Periphery** target zone represents areas with discontinuous NAPL that are located near the south and southwest portions of the FPA. This target zone is characterized by NAPL present in isolated pockets. The quantity ~~volume~~ of NAPL present in this area ~~-contaminated soil is estimated at 4,0300 CY, and this volume~~ is estimated at~~o contain~~ 33,0~~1~~00 gallons, which represents about 5 percent of the NAPL present in the Upper Aquifer ~~of NAPL or 7.7 gallons per CY of NAPL-contaminated soil~~.

The target zones also include **North Shallow and Deep** area, which is an overlap of the North Shallow (LNAPL) Periphery and North Deep (DNAPL) Periphery target zones located on the north end of the FPA. This zone is characterized by NAPL present in Compartment 2. The ~~v~~quantity ~~olume~~ of NAPL present in this area ~~-contaminated soil in this target zone is estimated at 3,000 CY and this volume~~ is estimated at~~o contain~~ 18,000 gallons of NAPL or 3 percent of the NAPL present in the Upper Aquifer ~~or 5.4 gallons per CY of NAPL-contaminated soil~~.

1.2.3.2 Aquitard

There are no monitoring wells or piezometers within the Aquitard, and only limited borings have been advanced through it. Consequently, creosote as NAPL or as dissolved constituents in Aquitard pore water cannot be directly measured. Instead, indirect observations and estimates must be relied on to evaluate the extent of NAPL contamination in the Aquitard. The following observations are informative in evaluating NAPL extent in the Aquitard:

- NAPL is present at the base of the Upper Aquifer at varying thicknesses and volumes in certain areas of the FPA. This indicates there is potential for downward NAPL migration into the Aquitard. However, penetrating the Aquitard is likely limited due to the heights (~~e.g~~i.e., thickness) that NAPL must pool to overcome the entry pressures present in the Aquitard. The critical pool height for NAPL to penetrate the Aquitard is estimated at 9.4 feet.[1] Once exceeded, the NAPL head increases with penetration into the Aquitard, and unless the pool height decreases, NAPL migration will continue through the Aquitard.

- NAPL is present in the Lower Aquifer in an area to the north of Lower Aquifer wells (VG-2L, P-3L, and CW15). NAPL has migrated to this area from the Upper Aquifer, but the migration pathway is unclear.

- Lower Aquifer groundwater quality monitoring has identified two areas with PAH constituent concentrations greater than clean-up levels specified in the 2000 ROD: one to the north encompassing monitoring wells CW05, CW15, P-3L, and VG-2L and the other to the southwest surrounding piezometer PZ-11.

[1] The critical NAPL pool height was estimated as described in Appendix A, *2013 Conceptual Site Model Update for the OU2 and OU4 Former Process Area* (CH2M HILL, 2013a).

- The Aquitard is thin to absent near PZ-11. Consequently, the potential migration of dissolved-phase constituents from surface contamination to the Lower Aquifer is not inhibited in this area. It is unclear whether NAPL is present in the Lower Aquifer in this area.
- The Aquitard thickness varies over portions of the Site where NAPL is present at the base of the Upper Aquifer. The Aquitard's slope and thickness, capillary forces, and NAPL pool height control the potential for NAPL penetration and migration through the Aquitard to the Lower Aquifer.

Interpreting these lines of evidence on **Figure 1-10** suggests that the presence of NAPL and dissolved constituents in the Aquitard is likely in the northern portion of the FPA and possible in the center of the FPA. At the north end of the Site, Lower Aquifer water quality effects align with NAPL thicknesses observed in the Upper Aquifer that exceed the required height for NAPL entry into the Aquitard (as observed at TarGOST location 2013T-043). Furthermore, the Aquitard thickness is estimated to be thinner in this vicinity at approximately 8 to 25 feet, and the Aquitard surface itself is thought to have several depressions where NAPL could pool.

Commented [YCK(5]: ? Perhaps results?

Commented [YCK(6]: and overcoming the entry pressures present in the Aquitard.

1.2.3.3 Lower Aquifer

The distribution of NAPL in the Lower Aquifer was estimated from NAPL thickness measurements made at Lower Aquifer monitoring wells during the June 2012 groundwater sampling event (CH2MHILL, 2013d). These measurements, as indicated by creosote staining on the measuring tape - although no defined oil-water interface was detected by the interface probe, indicate the presence of NAPL in four~~three~~ Lower Aquifer wells (CW15, P-3L, ~~and~~ VG-2L, and VG-5L) in the northern portion of the FPA. This corresponds with an area where acenaphthene and other PAH constituents (**Figure 1-11**) are consistently detected near or above the 2000 ROD groundwater clean-up levels.

Commented [YCK(7]: I thought that CH did not have an oil-water interface unit that can reach down to the lower aquifer.

1.2.4 Contaminant Fate and Transport

The coal-tar creosote used at the Wyckoff Site was a complex mixture of chemicals, containing many different compounds. Approximately 85 percent of these compounds are classified as PAHs and 2 to 17 percent as phenols (Bedient et al., 1984). Historical laboratory analysis of creosote samples collected from the Site shows that naphthalene accounts for most of the overall PAH composition (**Figure 1-12**). To improve penetration during the wood-treatment process, creosote and PCP were mixed with a carrier oil, which is presumed to have been diesel. The carrier oil is often indicated by the presence of benzene, toluene, ethylbenzene, and xylenes (BTEX) and total petroleum hydrocarbon (TPH) – diesel (TPH-Dx) concentrations in NAPL samples.

Wood-treating NAPL is subject to naturally occurring physical-chemical processes that, over time, result in transfer of contaminant mass from the NAPL to the vapor, aqueous, and solid-sorbed phases. Collectively, these processes reduce the mass of the NAPL source. Contaminants that partition from the NAPL to the vapor phase, and from the NAPL to the aqueous phase, may undergo further biologically mediated degradation and non-biologically mediated degradation reactions that reduce their concentrations in environmental media.

Volatilization is a process by which chemical compounds partition from the NAPL to a vapor and, hence, is an important process for NAPL present above the water table. The compounds present in NAPL at the Wyckoff Site that likely exhibit some volatilization behavior include naphthalene and benzene. Volatilization depends on soil temperatures with higher temperatures promoting higher rates of volatilization. The composition of NAPL present above the water table at the Site is expected to have been significantly affected by the loss of benzene and naphthalene.

Solubilization, or dissolution, is a process by which chemical compounds partition from the NAPL present above the water table to infiltrating rainfall or to groundwater for NAPL present below the water table. For multicomponent NAPLs, the solubilization process is governed by the compound's fractional concentration~~mole fraction~~ in the NAPL mixture and the water flux that moves across the NAPL zone. The chemical compounds present in NAPL at the Site have a wide range of aqueous solubilities with BTEX and low-molecular weight PAHs (LPAHs), such as naphthalene, acenaphthylene, and acenaphthane, most likely to be removed from the NAPL through solubilization.

Chemical compounds removed from the NAPL through solubilization can undergo non-biologically mediated ~~abiotic~~ and biologically mediated ~~biotic~~ degradation in groundwater under aerobic and anaerobic conditions. Biodegradation is ~~expected to be~~ an important process at the Site for many of the BTEX compounds and for the LPAHs, such as naphthalene. To assess potential rates of NAPL depletion resulting from dissolution and biodegradation, the mass of naphthalene present in the 679,000 gallons of NAPL ~~and Up~~was~~per Aquifer dissolved-phase plume were~~ calculated. Naphthalene was used as an indicator because it accounts for most of the NAPL mass per **Figure 1-12**. The amount of naphthalene present in the NAPL phase was estimated at 1.15 million kilograms[2]~~, and the mass of naphthalene present in Upper Aquifer groundwater estimated at 1,400 kilograms~~. The amount~~mass~~ of naphthalene present in the NAPL phase was estimated based on the assumption~~s~~ that: 1) ~~mass initially present presumes that~~ 85 percent of the NAPL mixture is comprised of ~~s~~ LPAH compounds, and 2) ~~of this fraction,~~ naphthalene comprises 50 percent ~~accounts for one-half~~ of the LPAH mass in the NAPL phase. This is equivalent to naphthalene accounting for 43 percent of the total PAH mass. This fractional composition is also consistent with more recent laboratory analysis of NAPL samples, which showed that naphthalene accounts for approximately 40 to 50 percent of the total SVOC mass in the LNAPL samples and 30 to 40 percent of the total SVOC mass present in the DNAPL samples.

To estimate PAH concentration half-life, two sets of historical NAPL composition data were evaluated. The first sample was collected in 1999 and the second in 2014. The changes in PAH concentration between these two NAPL samples were used to calculate an effective groundwater concentration for each major PAH constituent. The effective concentrations were then used to calculate a half-life for several PAH constituents. The calculated half-life for naphthalene was estimated at 30.4 years while PCP was estimated at 15.7 years. The half-life estimates are comparable to those reported for other creosote sites, although values for naphthalene vary widely. The estimated half-life value incorporates NAPL dissolution, biodegradation, and other weathering and mass transfer limitation effects.

The naphthalene half-life yields mass removal rates that approach about 22,000 kilograms per year initially eventually declining to less than 1,000 kilograms per year in about 140 years ~~A biodegradation half-life of 258 days, obtained from the literature (EPA, 1999), was then applied to the dissolved-phase naphthalene plume and an annual removal rate of 1,381 kilograms estimated. This removal rate was then applied to the total mass of naphthalene present in the NAPL to create a decline curve~~ (**Figure 1-13**). Assuming that the naphthalene dissolution is not rate controlled, and there are no other biodegradation rate limitations (e.g., nutrients, salinity or microorganism availability), it takes approximately 4~~8~~00 years for the initial naphthalene mass of 1.15 million kg to decrease to less than 100 kg. ~~all naphthalene present in the NAPL to partition and biodegrade.~~ This estimate assumes ideal conditions. In reality, as the NAPL composition changes with time, some other form of rate controls will begin to influence the rate of naphthalene dissolution resulting in a much longer timeframe.

[2] 679,000 gallons of NAPL * 3,785 milliliters/gallon * 1.021 grams/milliliter (NAPL density) * 0.001 kilograms/gram * 0.85 * 0.5 = 1,150,000 kilograms of naphthalene.

Other key NAPL fate and transport behavior at the Site includes the following:

- As the spills and leaks occurred, the contaminants moved as mobile NAPL into the vadose zone, adsorbing onto soil, volatilizing into soil gas, and dissolving into pore water.
- Mobile NAPL migrated downward through the vadose zone until it reached the water table and separated into light and dense phases:
  - The LNAPL spread out along the water table surface and migrated laterally with the groundwater.
  - Downward migration of DNAPL was slowed or halted as it encountered higher-density saline groundwater and lower-permeability zones within the Upper Aquifer. Some DNAPL continued migrating downward until it reached the Aquitard.
  - Lateral movement of DNAPL has occurred through high-permeability gravel and cobble zones or through spreading when the DNAPL reached low-permeability zones within the Upper Aquifer or at the top of the Aquitard.
  - NAPL undergoes dissolution as it encountered groundwater in the Upper Aquifer, resulting in formation of a multicomponent dissolved-phase plume characterized primarily by the presence of LPAH compounds. The aqueous-phase contaminants were then transported with the groundwater flow, laterally toward Eagle Harbor and Puget Sound.

Following are potential mechanisms for transport of contaminants to the Lower Aquifer:

- Leakage of DNAPL or dissolved contaminants through “holes” and sand zones in the Aquitard. Downward advective transport of dissolved contaminants through the Aquitard is considered unlikely under natural conditions or containment pumping, because the hydraulic head is higher in the Lower Aquifer than in the Upper Aquifer creating a net upward flow potential.
- Transport of DNAPL across the Aquitard by water displacement or ”wicking” mechanisms.
- Leakage of DNAPL or dissolved contamination as a result of early drilling activities on the Site, which may have provided conduits through the Aquitard. In 1995, EPA decommissioned 12 old wells. These were industrial water supply wells, monitoring wells, groundwater/contaminant extraction wells, and two deep drinking water supply wells.
- Transport of dissolved contaminants by molecular diffusion across the Aquitard from DNAPL on top of the Aquitard.

Any dissolved contaminants reaching the Lower Aquifer may~~would~~ be carried by regional groundwater flow toward discharge areas deep in Eagle Harbor and Puget Sound. However, due to the long transport distances involved, and assuming the groundwater is not extracted for beneficial use, any contaminants reaching the Lower Aquifer would likely be removed by sorption and decay before discharge to ~~the~~ surface water~~s~~.

1.2.5 Baseline Risk Assessment

No new Soil and Groundwater OUs risk assessment evaluation has been performed since the 2000 ROD was issued (EPA, 2000). Therefore, risks posed to human health and the environment by current conditions are expected to be comparable with those described in Section 7 of the 2000 ROD. Risk assessment to specifically characterize the threat to human health and the environment by NAPL has not been performed, but direct exposure to NAPL is generally recognized to likely pose human health risk exceeding the upper bound of the CERCLA 1 x10^{-4} to 1 x 10^{-6} excess lifetime cancer risk range.

1.2.6 Status of Current Containment Remedy

In February 2000, EPA issued the 2000 ROD for the upland portion of the Wyckoff Site addressing contaminated soil (OU2) and groundwater (OU4). The selected remedy, thermal remediation, included a number of components designed to achieve substantial risk reduction by cutting off subsurface contaminant migration pathways with a sheet pile wall and treating the principal threat at the Site using thermal technology. A thermal remediation pilot study was conducted between October 2002 and April 2003. Numerous technical difficulties were encountered and it was determined that cleanup objectives could not be met using this technology.

The 2000 ROD identified a contingent remedy to be implemented should the thermal remediation pilot test did not achieve its performance objectives. The contingent remedy – containment – is still in operation today and consists of the following components:

- Groundwater Extraction and Treatment. This includes nine recovery wells (**Figure 1-14**) screened in the Upper Aquifer. Pumps installed in these wells draw groundwater and NAPL away from the site perimeter and in toward the extraction wells. The groundwater and NAPL recovered from the extraction wells are treated in the onsite GWTP.
- Sheet-pile Wall – the 1,870 foot long steel sheetpile wall was constructed around the shoreline of the FPA to prevent potential flow of contaminants to Eagle Harbor.
- Long-Term Monitoring – provides data on water levels in both the Upper and Lower Aquifers beneath the FPA (for confirming hydraulic containment), and on contaminant distribution and movement in the subsurface. Monitoring is on-going.
- Institutional and Engineering Controls – prevent access to contaminated areas. Engineering controls (e.g., fencing) have been implemented to prevent contact with contaminated soil while ICs prevent groundwater withdrawals except for monitoring and remediation purposes.

The Washington State Department of Ecology (Ecology) assumed operation of the groundwater extraction and treatment system in 2012, pursuant to a State Superfund Contract (SSC). The original SSC expired in April 2014 and has been extended to June 2016. The system is effective in preventing further degradation of the Lower Aquifer. However, it is expensive to operate. Annual operation and maintenance costs are about $800,000 per year. At the current rate of PAH extraction and degradation, more than 300 years of additional pump and treat operations would be required to meet cleanup goals.

~~A substantial amount of work has been completed since issuance of the 2000 ROD, including the following . major activities:~~

- ~~Installation of a 1,870-foot-long sheet pile wall around the north and east perimeter of the FPA. A shoreline protection system to protect the wall has not been constructed.~~
- ~~Construction of a new 80-gallons per minute (gpm) groundwater treatment plant (GWTP) and demolition of the old GWTP.~~
- ~~Upgrades to the existing groundwater extraction and water level monitoring systems.~~

~~The groundwater extraction system consists of groundwater and NAPL pumping from nine Upper Aquifer extraction wells (**Figure 1-14**), routine water level measurements to assess hydraulic containment, and periodic groundwater sampling to assess contaminant concentration trends in the Lower Aquifer.~~

Based on recent performance, the groundwater extraction system removed about 22 million gallons ~~were extracted~~ from April 2012 through March 2013. The monthly groundwater extraction rate for all nine extraction wells ~~during this period~~ varied from 0 gallons per month in August 2012 to 3,381,757 gallons per month (77.2 gpm) in December 2012. Groundwater pumping rates generally follow a seasonal pattern that correlates with monthly rainfall. Average pumping rates were 1.6 gpm to 9.5 gpm at individual wells. Approximately 72 percent of the groundwater currently extracted comes from ~~from April 2012 through March 2013 was supplied by~~ four wells (RPW1~~2~~, RPW2~~4~~, RPW5, and RPW6~~7~~).

From March 2012 through March 2013, approximately 1,300 gallons of NAPL (120 gallons LNAPL and 1,180 gallons DNAPL) were removed from seven recovery wells (RPW1, RPW2, RPW4, RPW5, RPW6, RPW8, and RPW9). Approximately 90 percent of the NAPL recovered during this period was from four wells (RPW1, RPW2, RPW5, and RPW8). In addition to the NAPL pumped directly from the extraction wells, an estimated 2,900 gallons of NAPL was removed from the GWTP tanks during the same time period for a total of 4,200 gallons of NAPL recovered between March 2012 and March 2013.

The hydraulic containment system also removes dissolved-phase contaminant mass through the GWTP. Based on the average influent flow rate and average influent total PAH concentration, about 3,600 pounds of dissolved-phase contaminant mass was removed between March 2012 and March 2013.

The containment remedy is effective at maintaining an~~n inward horizontal groundwater flow gradient in the Upper Aquifer and maintaining an~~ upward vertical gradient from the Lower Aquifer to the Upper Aquifer. The upward gradient is evaluated quarterly by downloading water level data from pressure transducers installed in 10 Upper and Lower Aquifer monitoring well pairs, calculating average groundwater elevations for defined measurement periods, and comparing the Upper and Lower Aquifer groundwater elevations for each period. If the Lower Aquifer groundwater elevation is higher than the Upper Aquifer groundwater elevation, then an upward vertical gradient is present. When the containment system is operating, it protects marine water quality by reducing or eliminating the discharge of dissolved-phase contaminants to Eagle Harbor and Puget Sound.

SECTION 2

2 Identification and Screening of Technologies

As described in Section 1.1, the FFS consists of three phases:

- Screening remedial technologies
- Developing remedial action alternatives
- Conducting a detailed analysis of the alternatives

This s~~chapter~~ection presents the approach and results of the remedial technology screening phase. The technologies retained from the screening described in this ~~chapter~~~~S~~section are assembled into a range of source area remedial action alternatives that are detailed in ~~Chapter~~Section 3 and evaluated in ~~Chapter~~Section 4 to assist in identifying a recommended alternative that is presented in ~~Chapter~~Section 5. The remedial technology screening phase is preceded by the development of RAOs and preliminary remediation goals (PRGs) that define the clean-up levels that need to be achieved in soil and groundwater to protect human health and the environment.

2.1 Remedial Action Objectives

RAOs are narrative statements that describe what the remedial action is intended to accomplish. The RAOs may identify the contaminants of concern (COCs) and environmental media of concern, the exposure pathways to be protected, and the levels of clean-up that need to be achieved.

The RAOs developed by EPA and Ecology for the Wyckoff Soil and Groundwater OUs are provided in Table 2-1 and are described as follows:

- **RAO #1—**Prevent human health risks associated with direct contact, ingestion, or inhalation of shallow soil contaminated above levels for unrestricted outdoor recreational use.

  The designated future use of the Site is a public park. By cleaning up contaminated soil to a depth of 15 feet, the designated point of compliance under WAC 173-340-740 (6), or placing a barrier with ICs to prevent direct contact with surface soils, future recreational users will be protected from exposure to contaminants~~ present at concentrations above the clean-up levels presented in Section 2.2~~.

- **RAO #2—**Prevent use of Upper Aquifer groundwater for drinking water, irrigation, or industrial purposes which would result in unacceptable risks to human health.

  Due to elevated salinity, Upper Aquifer groundwater is designated as Class III, which makes it nonpotable and most likely unusable for most industrial or irrigation uses. However, the concentration of COCs present in Upper Aquifer groundwater would pose a threat to human health should long-term exposure occur. Therefore, this RAO was established to prevent the withdrawal of Upper Aquifer groundwater for drinking, irrigation, or industrial purposes. Groundwater withdrawal for monitoring and remediation is allowable and noncontact industrial uses may also be allowable as approved by EPA and Ecology on a case-by-case basis.

- **RAO #3—**Prevent discharge of contaminated Upper Aquifer groundwater to Eagle Harbor and Puget Sound resulting in surface water contaminant concentrations exceeding the levels protective of beach play, aquatic life, and human consumption of resident fish and shellfish.

Commented [MS8]: Deleted sentence below because soil PRGs are being eliminated.

Under natural groundwater flow conditions, Upper Aquifer groundwater flows toward Eagle Harbor and Puget Sound upwelling into the water column through seeps and diffuse flow across the intertidal and subtidal sediments. After the outer sheet pile wall was installed in February 2001, the groundwater flow path was altered reducing the natural flux to Eagle Harbor and Puget Sound. However, small amounts of leakage through the sheet pile wall joints do occur. This RAO was established to prevent contaminated Upper Aquifer groundwater from discharging to surface water at concentrations that would result in unacceptable risks to recreational users (fishers, shellfish gathers, or beach play), consumers of resident fish and shellfish, and Eagle Harbor or Puget Sound aquatic life.

- **RAO #4—**Minimize further degradation of ~~Restore~~ the Lower Aquifer and prevent the use of Lower Aquifer groundwater, which would result in unacceptable risk to human health~~to beneficial use within a reasonable timeframe. Prevent use of Lower Aquifer groundwater, which would result in unacceptable risk to human health until restoration goals are met~~.

  As described in Section 1.2, Lower Aquifer groundwater is designated as Class IIB (future drinking water source) except for those portions lying within 200 feet of the outer sheet pile wall where elevated salinity would likely preclude most uses. Human exposure is currently prevented through the use of access controls and ICs. Lower Aquifer groundwater within 200 feet of the outer sheetpile wall is not potable, but it discharges to Eagle Harbor, so protection of aquatic organisms is an important consideration. EPA is not selecting a remedy for the Lower Aquifer at this time. Through cleanup actions in the Upper Aquifer, EPA expects to prevent further degradation of the Lower Aquifer. EPA will monitor contaminant concentrations during and after cleanup actions in the Upper Aquifer and collect data needed to determine whether Monitored Natural Attenuation might be an effective remedy for the Lower Aquifer. A cleanup decision will be made for the Lower Aquifer in a future CERCLA decision document.~~This RAO was established to restore the portions of the Lower Aquifer that have been impacted by historical wood-treating activities and lie more than 200 feet inland of the outer sheet pile wall to a drinking water beneficial use as defined by maximum contaminant levels (MCLs). For those portions of the Lower Aquifer subject to saltwater intrusion (e.g., areas lying within 200 feet of the outer sheet pile wall), the groundwater would be restored to levels protective of aquatic life at the point of discharge to surface water.~~

2.1.1 Performance Objectives

In addition to the four RAOs described above, the following two performance objectives were also established by EPA and Ecology:

- **Performance Objective #1—**Remove or treat mobile NAPL in the Upper Aquifer to the maximum extent practicable such that migration and leaching of contaminants is significantly reduced. This will remove principal threat materials, which allows for considering monitored natural attenuation (MNA) as a remedial action technology for residual concentrations, and allows for implementing Performance Objective #2.
- **Performance Objective #2—**Implement a remedial action that does not require active hydraulic control as a long-term component of operations and maintenance (O&M) following completion of source removal action.

These objectives were used to guide the development of the remedial action alternatives presented in ~~Chapter~~Section 3 of this FFS. Relative to Performance Objective #2, hydraulic control may be used during the active remediation phase, but not for the long term. A 10-year period of hydraulic control following completion of all source removal activities is assumed as the maximum allowable duration for active hydraulic control in this FFS.

2.1.2 Contaminants of Concern

Following are the soil and groundwater COCs identified in the 2000 ROD:

- PAHs also present in the NAPL
- PCP also present in the NAPL
- Dioxins/Furans (soil only) are typically associated with PCP and, therefore, are inferred to be present in NAPL

Each of the above represents a specific contaminant or group of contaminants that are known through laboratory analysis or process knowledge to be associated with historical wood-treating activities conducted in the FPA. No additional NAPL related COCs have been identified.

For this FFS, other contaminants—such as BTEX, which is associated with the carrier oil that is blended with creosote and PCP-based wood-treating oils, and heterocyclic aromatic compounds (e.g., 2-methylnaphthelene, carbazole, and dibenzofuran)—are assumed to be ~~colocated~~collocated with the PAHs and PCPs and will be remediated along with these primary COCs.

2.1.3 Preliminary Remediation Goals

PRGs represent the allowable concentration of COCs in environmental media that are protective of human health and the environment. Therefore, they define the level of clean-up to ~~hat must~~ be achieved at the completion of a remedial action. PRGs are defined based on expectations for land, groundwater, and interconnected surface water beneficial uses. PRGs are also used to identify the area and/or volume of contaminated media to be addressed by a soil and/or groundwater remedial action. However, this FFS develops and evaluates remedial action alternatives designed to address NAPL source material. Therefore, the area/volume of contaminated material is not defined by a soil or groundwater PRG but by areas where NAPL occurs. EPA and Ecology agreed to use a TarGOST 10%RE measurement value as an indication of NAPL presence. Areas with a TarGOST response of 10%RE or greater are presumed to contain NAPL and areas with a TarGOST response of less than 10%RE are presumed to not contain NAPL.

The RAOs presented in Section 2.1 are expected to require a level of NAPL remediation and/or exposure control that accomplishes the following:

- Protects human health from exposure to NAPL-contaminated material present within the ground surface to a 15-foot depth. ~~Future Site use may expose individuals to NAPL-contaminated material present in this depth interval that is brought and spread at the surface during development activities.~~
- Restores Upper Aquifer groundwater quality to a level that protects marine surface water quality and aquatic receptors.
- Protects ~~Restores~~ Lower Aquifer groundwater, that is suitable as a drinking water source, from further degradation ~~quality to a level that allows for future drinking water use in the portion of the FPA not affected by saltwater intrusion~~. Groundwater within the potable portions of the Lower Aquifer underlying the FPA does not currently contain COCs at concentrations above MCLs.

Owing to the technical challenge associated with remediating sites with large areas/volumes of NAPL contamination, it is not known what fraction of the NAPL present within the area enclosed by the TarGOST 10% RE isopach must be remediated to achieve the RAOs. F~~Absent this information, and f~~or the purposes of this FFS and remedial action alternative development, it is presumed that ~~a~~ much ~~high level~~

Commented [YCK(9]: This might be too broad. I think we are only targeting localized areas, the passive treatment/discharge areas.

~~(e.g., greater than 90 percent)~~ of the NAPL contaminated ~~source~~ material lying within the Upper Aquifer beneath the FPA will have to be treated.

The following subsections summarize the regulatory and technical approach used to develop soil and groundwater PRGs. These PRGs are preliminary and will be finalized in the CERCLA decision document.

2.1.3.1 PRG Development Approach

PRGs for contaminants present in soil and groundwater are generally defined by state and federal regulations. These regulations are identified through a comprehensive review of ARARs. The Soil and Groundwater OUs ARARs review (**Appendix A**) was conducted in accordance with "Cleanup Standards," "Degree of Cleanup" (CERCLA [Section 121(d)]) and CERCLA RI/FS Guidance (EPA/540/G-89/004; EPA, 1991); *CERCLA Compliance with Other Laws Manual: Interim Final* [EPA/540/G-89/006; EPA, 1988]; and *CERCLA Compliance with Other Laws Manual: Part II* [EPA/540/G-89/009; EPA, 1988]). Section 121(d) of the CERCLA statute, requires, with exceptions, that any promulgated substantive ARAR standard, requirement, criterion, or limitation under any federal environmental law, or any more stringent state requirement pursuant to a state environmental statute, or facility siting law be met (or a waiver justified) for any hazardous substance, pollutant, or contaminant that will remain on Site after the remedial action has concluded. The NCP ("Remedial Design/Remedial Action, Operation and Maintenance," 40 CFR 300.435[b][2]) requires that ARARs be attained (unless waived) during the remedial action.

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Potential ARARs for the Soil and Groundwater OUs were identified and reviewed to group them into one of three categories as follows:

- **Chemical-specific ARARs—**These include health- or risk-based numerical values or methodologies that, when applied to site-specific conditions, establish public and worker clean-up levels (e.g., PRGs).
- **Location-specific ARARs—**These include restrictions placed on the concentration of dangerous substances or the conduct of activities solely because they occur in special geographic areas.
- **Action-specific ARARs—**These are technology- or activity-based requirements or limitations triggered by remedial actions performed at a site.

The chemical-specific ARARs applicable to the Wyckoff Soil and Groundwater OUs remedial actions are the elements of the WAC that implement the Model Toxics Control Action (MTCA) regulations. Within WAC 173-340, Cleanup, there are detailed regulations specifying soil ("Unrestricted Land Use Soil Cleanup Standards" [WAC 173-340-740]) and groundwater ("Groundwater Cleanup Standards" [WAC 173-340-720]) clean-up standards. These standards are in the form of risk-based concentrations that define soil, groundwater, and air clean-up standards for chemical contaminants. Following is a list of other chemical-specific ARARs:

- Substantive portions of MTCA, including "Selection of Cleanup Actions" (WAC 173-340-360) and "Overview of Cleanup Standards" (WAC 173-340-700) through "Priority Contaminants of Ecological Concern" (WAC 173-340-7494) that also includes "Cleanup Standards to Protect Air Quality" (WAC 173-340-750), "Sediment Cleanup Standards" (WAC 173-340-760), and "Sediment Management Standards" (WAC 173-204)
- Nonzero MCL goals and MCLs promulgated under the Safe Drinking Water Act (SDWA), "National Primary Drinking Water Regulations" (40 CFR 141) and/or by the State of Washington ("Group A Public Water Supplies" [WAC 246-290]) as they apply to primary MCL constituents

- Ambient water quality criteria (AWQC) and state water quality standards at the groundwater/surface water interface developed under the CWA (Section 304) and/or promulgated by the state of Washington ("Water Quality Standards for Groundwaters of the State of Washington" [WAC 173-200] and "Water Quality Standards for Surface Waters of the State of Washington" [WAC 173-201A]), "National Pollutant Discharge Elimination System [NPDES] Permit Program" [WAC 173-220], and "Wastewater Discharge Standards and Effluent Limitations" [WAC 173-221A].

2.1.3.2 Soil

The State of Washington MTCA regulation is the principal ARAR governing the development of PRGs for environmental clean-up actions. As set forth in WAC 173-340-700(2), remedial actions shall attain the following:

Numeric clean-up levels for all COCs

- Clean-up levels at defined locations termed the points of compliance

Numeric clean-up goals that define human health protectiveness for soil are presented in **Table 2-2**. These levels are based on MTCA, Method B (WAC 173-340-740) unrestricted use, which potentially represents a level of clean-up that is more conservative than necessary based a future recreational site use. During development of the final remedial goals for inclusion in the CERCLA decision document, if allowed by Ecology, these PRGs may be adjusted upward to reflect the lower exposure frequency associated with a recreational land use. The clean-up levels presented in Table 2-2 are based on an excess lifetime cancer risk (ELCR) of 1 x 10^{-6}. Because NAPL-contaminated soil and groundwater contain multiple carcinogenic COCs, the 1 x 10^{-6}-based clean-up levels presented in Table 2-2 will need to be adjusted downward when developing final remedial goals to satisfy the 1x10^{-5} MTCA requirement. A similar adjustment will also be required for the noncarcinogenic COC to satisfy WAC 173-340-708(5)(c).

The point of compliance for the soil PRGs that protect human health extends from the ground surface to a depth of 15 feet bgs. This represents a reasonable estimate of the depth where soil could be excavated and distributed at the surface as a result of unrestricted development activities. If future development of the Site for recreational purposes does not include intrusive subsurface activities, then an alternate point of compliance could be established in the CERCLA decision document.

~~In addition to protecting human health, soil-based PRGs must also be protective of Upper Aquifer groundwater quality through the leaching pathway. As described in Section 1.2, the beneficial use of Upper Aquifer groundwater is marine surface water recharge. Per WAC 173-340-747, Deriving Soil Concentrations for Groundwater Protection, a four-phase partitioning model employing site-specific data is required at sites contaminated with NAPL. The information necessary to support developing NAPL-contaminated soil PRGs that reflect current conditions is being obtained as part of the May 2014 Upper Aquifer groundwater sampling effort. These PRG calculations are recommended to be performed as part of the Upper Aquifer groundwater quality data evaluation and the results incorporated into the next version of this FFS report. Based on experience at other wood-treating sites, soil PRGs protective of groundwater and/or surface water quality are expected to be lower than the values presented in Table 2-2.~~

2.1.3.3 Upper Aquifer Groundwater

Upper Aquifer groundwater PRGs must protect marine surface water quality. The overall approach used to develop PRGs for each COC consisted of multiplying the lowest applicable marine AWQC by a dilution-factor (DF). The DF reflects the concentration reduction that occurs during COC transport along a flow path that extends from the Upper Aquifer, through or beneath the sheet pile wall, through the soil-sediment horizon, and terminating in the intertidal and subtidal sediments. As shown on **Figure 2-1**, the length of this flow path varies. Dissolved-phase COCs will experience different degrees of concentration reduction depending on the flow path length.

Once dissolved-phase COCs move through the sheet pile wall their concentrations will decrease as a result of two occurrences: (1) dilution due to tidal fluctuation and mixing and (2) biodegradation during groundwater transport.

Historical contaminant fate and transport modeling (CH2M HILL, 2004) estimated that COC concentrations would be reduced by a factor of 20 due to tidal dilution. Biodegradation and retardation processes will further reduce COC concentrations. For this FFS, only dilution was considered owing to uncertainty on biodegradation rates within the intertidal area where groundwater salinity levels increase.

As shown on **Table 2-3**, for many of the COCs, the lowest marine AWQC multiple by a DAF of 20 yields a concentration greater than its freshwater-single component aqueous solubility. Where this occurred, the Upper Aquifer groundwater PRG was set equal to one-half of the aqueous solubility. Due to the presence of NAPL outside the sheet pile wall, the Upper Aquifer groundwater point of compliance would occur just inside the sheet pile wall. The NAPL present outside of the sheet pile wall will be addressed by the East Harbor OU1 remedy.

2.1.3.4 Lower Aquifer Groundwater

With respect to Lower Aquifer groundwater, the approach consisted of reviewing federal and state ARARs and selecting the most conservative drinking water standard for each COC (**Table 2-4**). The point of compliance for the Lower Aquifer is the south and west boundaries of the FPA.

Commented [YCK(12]: For MCL, the point of compliance should be anywhere within the potable region of the lower aquifer under the FPA.

2.2 General Response Actions

General response actions (GRAs) are typically media-specific actions that are appropriate for the site conditions, COCs, and RAOs. GRAs may include either individual or combinations of the following:

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- No action
- Access restrictions, including institutional controls (ICs) and engineering controls (ECs)
- Containment
- Removal and disposal (on-site and off-site)
- Ex situ treatment (on-site and off-site)
- In situ treatment

Because this FFS focuses on NAPL source material, the GRAs were not segregated by soil and groundwater. Sections 2.2.1 through 2.2.5 provide a general description of each GRA.

2.2.1 No Action

This GRA is required as a baseline for comparison against other technologies as specified under the NCP (40 CFR 300.430[e][6]). Under this GRA, no further action is taken at a site. If interim or final actions have been completed or are underway at the time of remedy selection, they are terminated following ROD or ROD amendment signature.

2.2.2 Access Restrictions

This GRA includes ICs and ECs. ICs are administrative controls or legal restrictions placed on land and groundwater use to protect the public against inadvertent exposure to hazardous constituents and/or to protect the integrity of a functioning or completed remedy. ICs may include land use restrictions, natural resource use restrictions, groundwater use restrictions or management areas, property deed notices, declaration of environmental restrictions, access controls (digging and/or drilling permits), surveillance, information posting or distribution, restrictive covenants, and federal, state, county, and/or local registries.

ECs generally include fences or manned security to protect against trespasser exposure to contaminated soils or groundwater (seeps and/or springs) until RAOs are achieved. For groundwater, ECs may include providing an alternate water supply for current or future users when contaminated groundwater is identified as a current drinking water source.

The existing containment remedy for the Site uses access restrictions to reduce the potential for human exposure to contaminated media present in the Former Process Area.

2.2.3 Removal and Disposal

These GRAs include excavation to remove contaminated media with long-term containment and management provided by disposing of the material at a secure on-site or a permitted off-site Resource Conservation and Recovery Act (RCRA) Subtitle D or Subtitle C facility. Depending on the concentration of contaminants present, disposal may be combined with ex situ treatment to comply with RCRA land disposal restrictions.

2.2.4 Ex Situ Treatment

This GRA includes technologies employed at an on-site or off-site treatment facility that treat contaminated media in aboveground treatment units. The current containment remedy uses ex situ physical treatment technologies (NAPL separation and granular activated carbon filtration) to treat NAPL, PAH, and PCP contamination in groundwater.

2.2.5 In Situ Treatment

This GRA includes various technologies (biological, chemical, thermal, physical) to treat contaminated media below the ground surface or in situ. MNA is also included within the scope of this GRA.

2.2.6 Area and Volume of NAPL Source Material Addressed

As described previously, EPA and Ecology agreed to use the TarGOST 10%RE measurement value as an indicator of NAPL presence. Additional information on the rationale used for selecting the 10%RE value is presented in the *Wyckoff Upland NAPL Field Investigation Technical Memorandum Field Summary Report* (CH2M HILL, 2013c). The area enclosed by the 10%RE TarGOST response was subdivided into five different geographic areas based on differences in NAPL volumes and NAPL architecture (e.g., LNAPL versus DNAPL). The location of these areas was described previously in Section 1.2.3 and shown on **Figure 1-7**.

The NCP establishes an expectation that EPA will use treatment to address the principal threats posed by a site wherever practicable (NCP CFR 300.430[a][l][iii][A]). Identifying principal threat wastes combines concepts of both hazard and risk. The manner in which principal threats are addressed generally determines whether the statutory preference for treatment as a principal element of the remedial alternative is satisfied in a CERCLA decision document.

Principal threat wastes are those source materials considered to be highly toxic or highly mobile that generally cannot be reliably contained or would present a significant risk to public health or the environment should exposure occur. The decision to treat these wastes is made on a site-specific basis through a detailed analysis of remedial alternatives, using the remedy selection criteria specified in the NCP. This analysis provides the basis for making a statutory finding that the selected remedy uses a proven treatment technology as a principal element. For this Wyckoff Soil and Groundwater OUs FFS, NAPL source material meets the definition of a principal threat waste. Contaminated groundwater is not considered a principal threat or low-level threat waste because it is not source material (EPA, 1991).

2.3 Identification and Screening Technologies and Process Options

This section identifies remedial technologies, and their associated process options, that are applicable to NAPL source material present in the Soil and Groundwater OUs. The remedial technologies were screened for their ability to achieve the RAOs and Performance Objectives described in Section 2.1 based on the CERCLA criteria of effectiveness; implementability; and relative cost. The technologies retained from the screening are combined into a range of remedial action alternatives in ~~Chapter~~Section 3 of this FFS report.

The technology screening step included a broad range of technologies applicable to wood-treating sites with an emphasis on treatment technologies that address NAPL source material. Additionally, because the remedial action timeframe is expected to span several to tens of years, technologies that protect human health and the environment during the remedial action were also emphasized. Factors considered in this evaluation include the state of technology development, site conditions, NAPL characteristics and distribution, and specific COCs that could limit a technology's effectiveness or implementability.

Sources of information considered for the technology screening included the following:

- Presumptive Remedies for Soils, Sediment, and Sludges at Wood Treater Sites (EPA, 1995)
- 1997 OU2/OU4 FS Report (CH2M HILL, 1997)
- Previous bench-scale and field-scale pilot studies
- CH2M HILL project experience on other wood-treating sites
- Federal Remediation Technologies Roundtable (FRTR, 2010)
- Interstate Technology and Regulatory Council (ITRC, 2009)
- Vendor information, case studies, and technical journal articles
- Information presented in the *Generational Remedy Evaluation* (Ecology, 2010)

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The technology screening includes many of the technologies retained in the OU2/OU4 FS Report (CH2M HILL, 1997) and technologies used under the current containment remedy.

2.3.1 Technology Screening Criteria and Methodology

The technology screening qualitatively assesses each technology's ability to achieve the RAOs and performance objectives using the CERCLA criteria of effectiveness, implementability, and relative cost as defined in the NCP (40 CFR 300.430[e][7]). Technologies that are not viable based on these considerations were eliminated from further consideration.

2.3.1.1 Effectiveness

Effectiveness refers to a technology's ability, and its associated process option(s), ~~ability and~~ to perform as a stand-alone or component of a broader alternative to meet RAOs under the conditions and limitations present at a site. Additionally, the NCP (40 CFR 300) defines effectiveness as follows: "…degree to which an alternative reduces toxicity, mobility, or volume through treatment; minimizes residual risk; affords long-term protection; complies with Applicable or Relevant and Appropriate Requirements (ARARs); minimizes short-term effects; and how quickly it achieves protection." Section 4.2.5 of CERCLA RI/FS Guidance (EPA, 1988) states that the evaluation of remedial technologies and process options with respect to effectiveness should focus on the following: "(1) the potential effectiveness of process options in handling the estimated areas or volumes of media and meeting the remediation goals identified in the RAOs; (2) the potential impacts to human health and the environment (HHE) during the construction and implementation phase; and (3) how proven and reliable the process is with respect to the contaminants and conditions at the site."

2.3.1.2 Implementability

Implementability refers to the relative degree of difficulty anticipated in implementing a particular remedial technology and process option under technical, regulatory, and schedule (administrative) constraints posed by a site. As suggested by CERCLA RI/FS Guidance (EPA, 1988), process options and entire technology types can be eliminated from further consideration if a technology or process option cannot be effectively implemented at a site. As discussed in Section 4.2.5 of CERCLA RI/FS Guidance (EPA/540/G-89/004), "technical implementability is used as an initial screening of technology types and process options to eliminate those that are clearly ineffective or unworkable at a site." Administrative implementability, which includes "the ability to obtain necessary permits for off-site actions, the availability of treatment, storage, and disposal services (including capacity), and the availability of necessary equipment and skilled workers to implement the technology," is also considered in the initial screening.

2.3.1.3 Relative Cost

For the initial screening of technology types and process options, the cost criterion is relative, meaning quantitative cost estimates are not prepared. Rather it compares remedial technology and process option costs using narrative terms. Section 4.2.5 of CERCLA RI/FS Guidance (EPA, 1988) states that "cost plays a limited role in the screening of process options. Relative capital and O&M costs are used rather than detailed estimates. At this stage in the process, the cost analysis is made on the basis of engineering judgment, and each process is evaluated as to whether costs are high, low, or medium relative to other process options in the same technology type." For this evaluation, relative cost is used to screen out process options that have a high capital cost if there are other choices that perform similar functions with similar effectiveness. Technology screening based on relative O&M costs was not specifically performed but was considered as part of the overall cost evaluation.

2.3.1.4 Assessment Methodology

The assessment of individual technologies and their associated process options was performed based on the criteria described above using a relative grading scale employing a "good," "moderate," or "poor" rating. To create greater separation, or where a technology's performance could vary within the different target zones at the Site, a blended rating such as poor to moderate or moderate to good was used. Once the assessment against each of the three criteria was completed, a "retained" or "not retained" determination was made.

2.3.2 Retained Technologies

Individual remedial technologies and their associated process options were screened based on considerations of effectiveness, implementability, and relative cost. The screening step is designed to narrow the list of remedial technologies to identify the most viable candidates for use in assembling remedial action alternatives. The technology screening and screening results are summarized in **Table 2-5**. Where appropriate, the technology screening also provides the justification for retaining or not retaining a technology for further consideration. The overall goal is to retain representative process options within the GRA's categories to form remedial alternatives. The remedial technologies and process options retained from the screening are summarized in **Table 2-6**. Individual technology and technology pairings assigned to each target zone are presented in **Table 2-7**.

SECTION 3

3 Development and Screening of Alternatives

This ~~chapter~~Section assembles the technologies retained from the screening performed in Section 2.3 into an array of NAPL source remedial action alternatives, presents a conceptual design for each alternative based on the representative process options, and then screens the alternatives to determine which ones should be carried forward for detailed evaluation in ~~Chapter~~Section 4.

3.1 Development of Alternatives

The NCP ("Remedial Investigation/Feasibility Study and Selection of Remedy," 40 CFR 300.430[e][3]) sets forth the following expectations for development of source control alternatives:

- *"A range of alternatives in which treatment that reduces the toxicity, mobility, or volume of the hazardous substances, pollutants, or contaminants is a principal element. As appropriate, this range shall include an alternative that removes or destroys hazardous substances, pollutants, or contaminants to the maximum extent feasible, eliminating or minimizing, to the degree possible, the need for long-term management.*
- *Alternatives, as appropriate, which, at a minimum, treat the principal threats posed by the site but vary in the degree of treatment employed and the quantities and characteristics of the treatment residuals and untreated waste that must be managed.*
- *One or more alternatives that involve little or no treatment, but provide protection of human health and the environment primarily by preventing or controlling exposure to hazardous substances, pollutants, or contaminants, through engineering controls, for example, containment, and, as necessary, institutional controls to protect human health and the environment and to assure continued effectiveness of the response action."*

In accordance with the above NCP expectations and the technologies retained from the screening performed in Section 2.3, a range of source control alternatives were assembled. While other technology and process option combinations are possible, technology combinations that are most viable based on the RAOs, performance objectives, and subsurface conditions present in each of the target zones were considered.

The proposed alternatives include the following (**Table 3-1**):

- Alternative 1—No Action (required per the NCP)
- Alternative 2—Containment (the current remedy)
- Alternative 3—Excavation, Thermal Desorption, and In Situ Chemical Oxidation (ISCO)
- Alternative 4—In Situ Solidification/Stabilization (ISS)
- Alternative 5—Thermal Enhanced Extraction and ISS
- Alternative 6—Excavation, Thermal Desorption, and Thermal Enhanced Extraction
- Alternative 7—ISS of Expanded Core Area and Thermal Enhanced Recovery~~Extraction~~

The alternatives listed above are identified by their primary technologies. However, exclusive of Alternative 1—No Action, each alternative requires supporting technologies to allow for full and

Formatted: List Bullet,List Bullet Double, Add space between paragraphs of the same style successful implementation. Section 3.2 describes these supporting technologies, which are identified as common elements, and Section 3.3 describes in detail the remedial action alternatives.

3.1.1 Preliminary Screening

After the technologies were assembled into a range of alternatives, preliminary engineering was performed to develop a design concept to identify technical and overall implementation considerations. Following this step, the alternatives were screened (see Section 2.3.1 for the definition of the screening criteria) per *The Feasibility Study: Development and Screening of Remedial Action Alternatives* (EPA, 1989). The purpose of the screening step is to determine whether any alternatives should be eliminated from further consideration based on effectiveness, implementability, or relative cost considerations. The alternatives retained from the screening step were carried forward for more detailed engineering and cost estimate development.

3.1.2 Conceptual Design

The level of engineering performed for the alternatives presented in Section 3.3 varies and is estimat~~xpect~~ed to range from 3 to 15 percent of that required to prepare a fully biddable and constructible remedial design.

The conceptual design for each alternative is based on the volume of NAPL contaminated soil present in each of the remedial action target zones listed in Table 1-2, and the characteristics of the NAPL present in the various Upper Aquifer Compartments (e.g. Compartment 1: LNAPL, and Compartments 2 and 3: DNAPL). During the conceptual design process, the areas and volumes of NAPL contaminated material treated by each alternative may have changed from that shown in Table 1-2. These changes are attributed to the logistics and performance expectations that are unique to each alternative's treatment technology.

For Alternatives 2 through 6, the volume of NAPL contaminated soil and quantity of NAPL present in each remedial action target area and Upper Aquifer Compartment is based on the 10% RE TarGOST response while under Alternative 7 the volume of NAPL contaminated soil and NAPL quantity is based on the 25% RE TarGOST response. As shown on Table 1-2, the 25% RE TarGOST response yields lower estimates of NAPL contaminated soil volume and NAPL quantities. However, the technologies used in each of the alternatives, and the overall design process, do not permit targeting or exclusion of discrete zones where NAPL may occur at concentrations corresponding to a TarGOST response of 10% RE to 25% RE. Therefore, while the volume of NAPL contaminated soil and NAPL quantity shown for Alternative 7 in Table 3-2 is different than estimated for the other alternatives it is expected that these quantities are comparable.

The actual areas and volumes of NAPL contaminated media addressed by the selected alternative will be refined during the remedial design using new information obtained from predesign investigations and more detailed evaluation of existing information. Additionally, the actual volumes of NAPL contaminated media treated and/or volumes of NAPL recovered by the selected alternative will also likely differ from that estimated in this FFS. This difference is attributed to subsurface heterogeneity and estimated versus observed performance of each remedial technology.

3.1.3 Cost Estimating

The cost estimates prepared for each retained remedial action alternative were developed per *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (EPA, 2000). The cost estimates are intended for comparison purposes and were prepared to meet the -30 to +50 percent range of accuracy recommended in the CERCLA RI/FS Guidance (EPA, 1988). Actual costs will depend on the final scope and design of the selected remedial action alternative, implementation schedule, competitive market conditions, and other variables. However, these factors are applicable to all alternatives and not expected to affect the relative cost differences between them. The cost estimates include allowances for the following items:

- Remedial design costs, including preparation of design drawings and specifications and construction bid documents, which were calculated as a percentage of the construction cost
- Remedial alternative construction costs, including construction management, capital equipment, general and administrative costs, and construction subcontract costs and fees, which are based on engineering judgment, cost estimating references, actual costs for similar work performed at other sites, and vendor quotes
- Annual short-term O&M including remedy performance monitoring and reporting costs for the estimated duration of the remedial action until RAOs are achieved. The term short-term O&M, as used in this FFS, refers to recurring costs associated with implementation of remedial action technologies over a multi-year period until RAOs are achieved. Long-term O&M costs associated with maintaining the remedy after RAOs have been achieved are not included in the cost estimate. Examples of long-term O&M costs include maintenance of a final site cap and maintenance of water balance (stormwater and groundwater elevation) control measures
- Equipment or remedy component replacement costs
- Project management, oversight costs, and preparation of CERCLA five-year reviews until RAOs are achieved

The total remedial action alternative life-cycle costs (see Appendix C) are presented as non-discounted (base year of 20164) and present worth values. The present worth cost-estimating method establishes a common baseline for evaluating costs that occur during different periods, thus allowing for direct cost comparisons between different alternatives. The present worth cost represents the dollars that would need to be set aside during the base year, which for this FFS is assumed to occur in 2016, at the defined interest rate, to ensure that funds would be available in the future, as they are needed to implement the remedial action alternative. Present worth costs were estimated using the 1.4 percent real discount rate published in *Appendix C - Discount Rates for Cost Effectiveness, Lease Purchase, and Related Analyses, Guidelines and Discount Rates for Benefit Cost Analysis of Federal Programs* (OMB Circular A-94), effective June 2016 and the 7 percent discount rate cited in *A Guide to Developing and Documenting Cost Estimates During the Feasibility Study* (EPA, 2000)4. Present worth costs calculated using the 7 percent discount rate are intended to show the sensitivity of each alternative's total present value cost to the discount rate.

3.2 Common Elements

The following subsections briefly summarize each common element. **Table 3-2** shows which common elements are associated with each alternative, while **Figure 3-1** shows the total common element cost for each alternative. Several common element descriptions include a reference to engineering drawings, which are provided in Appendix B.

3.2.1 Pre-Construction Activities

This common element is associated with Alternatives 2 through 7 and includes the following activities:

- Obtaining local and State permits as applicable
- Preparing subcontractor work plans, health and safety plans, activity hazard analysis, and project schedule

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- Mobilizing/demobilizing subcontractor general equipment
- Conducting community relations
- Preparing the Site and conducting a property survey
- Developing prorated remedial design, construction management, and project management costs.

The total estimated cost for this common element is $879~~69~~,000.

3.2.2 Access Road

Most equipment needed to implement the remedial action alternatives is large and will require delivery to the Site via trailer. The existing road has curves that are too sharp for large semitrailer trucks to navigate, and the 15 percent grade is too steep for trucks to maintain traction. This common element, which is required for Alternatives 2 through 7, includes realigning, regrading, and resurfacing the existing asphalt road (1,500 lineal feet) at an estimated cost of $306~~288~~,000 as shown on **Appendix B**, **Drawings 101-CE-100 and 101-CE-101**.

3.2.3 Concrete Demolition, Decontamination, and Reuse

Previous demolition conducted at the Wyckoff Site has primarily included aboveground equipment and facilities. Most of the equipment and building foundations, and other below ground concrete structures (primarily sumps), have not been removed. This common element removes buried concrete (**Appendix B**, **Drawing 101-CE-102**) that could prevent or significantly impede implementation of the subsurface components of Alternatives 3 through 7. The estimated cost for this common element is $2.3~~2~~ million.

The work associated with this element would occur before the remedial action alternative is implemented. All concrete would be removed and/or demolished, pressure-washed to capture creosote for off-Site disposal, and then crushed to segregate rebar and size the material for subsequent on-Site reuse. Recycling the rebar provides an estimated credit of $189,000. The area of concrete foundations and structures requiring demolition is estimated at 1.5 acres (7,200 square yards). The thickness of each foundation was conservatively estimated to be 2 to 3 feet based on the known previous use of the foundations. The total estimated volume of concrete is 8,000 CY.

3.2.4 Sitewide Debris Removal

Other buried utilities and debris (e.g., process pipes, storm drains, electrical conduit, and the wing wall) are also known to exist given the Site's long history. Under this common element, Sitewide subsurface debris would be removed (**Appendix B**, **Drawing 101-CE-102**) to allow the subsurface work required in Alternatives 3 through 7 to be implemented. The estimated cost for this common element in Alternatives 3 through 7~~6~~ is $3.2 million~~, and $1.1 million for Alternative 7~~. This work would include excavating an estimated 66,600 CY~~ (22,200 CY for Alternative 7)~~ of material and disposing of 670 CY (300 tons) of hazardous debris at an off-Site RCRA Subtitle C facility.

3.2.5 Bulkhead Removal

The area between the original Site bulkhead and the current outer sheet pile wall was filled with rock and concrete debris that must be removed (**Appendix B Drawing 101-CE-102**) to permit access for remediation of subsurface material up to the edge of the sheet pile wall under Alternatives 3 through 7. Under this common element, an estimated 17,000 CY of rock, 30,000 CY of other material, and 2,700 CY of bulkhead would be removed. Approximately 2,000 tons of this material would be transported and disposed at a RCRA Subtitle C facility and a similar amount disposed at a Subtitle D facility. The area would then be backfilled with 45,000 CY of clean soil and rock. The estimated cost for this common element is $8.8 million.

3.2.6 Other ~~and~~ Miscellaneous Demolition

This common element allows for decommissioning and disposing of the steam pilot plant area, equipment, and its associated infrastructure, and removal of an estimated 100 CY of PAH contaminated soil present in the vicinity of PZ-11. Under Alternatives 3 through 7, all pilot plant components would be demolished and disposed at an estimated cost of $2.8~~3.0~~ million. Under Alternative 2, all pilot plant components except the northwest beach sheet pile wall would be removed at an estimated cost of $1.3 million. It is assumed the equipment and contaminated soil will be disposed at a Subtitle D landfill.

3.2.7 Stormwater Infiltration Trench

This common element involves installing a stormwater infiltration trench along the southern boundary of the FPA to intercept and divert run-off away from the Alternatives 4 through 7 work area during construction of the alternatives before the final cap is placed. The estimated cost for the trench is $214,000.

3.2.8 Replacement Sheet Pile Wall

This common element includes replacing the outer sheet pile wall, which due to corrosion at and above the mud line (approximate elevation 5 feet), could fail within 10 to 20 years. The replacement sheet pile is required for installing the concrete perimeter bulkhead wall described in Section 3.2.9. Replacement includes installing 1,900 lineal feet of wall to an elevation ~~average depth~~ of -52.5~~75~~ feet (142,200 square feet total). The sheet pile wall would be replaced under Alternatives 2, 5, ~~and~~ 6, and 7 at an estimated cost of $13.4~~3~~ million.

3.2.9 Concrete Perimeter Bulkhead Wall

Under this common element, a new reinforced concrete wall would be constructed on the inside of the existing outer sheet pile wall (see **Appendix B, Drawing 101-CE-300**). The purpose of the wall is to provide geotechnical support to accommodate additional soil loading associated with reuse of remediation material and to promote post-remediation stability of the shoreline.

There are two~~three different~~ designs for the wall (**Appendix B**, **Drawing 101-CE-300**). The design under Alternatives 2, ~~3,~~ 5, ~~and~~ 6, and 7 which is estimated to cost $11.4~~2~~ million, involves installing a 1,900-foot-long wall to a depth of 38 feet. The design for Alternative~~s~~ 4 ~~and 7~~ is estimated to cost $8~~7~~.0~~9~~ million and involves constructing a 1,900-foot-long wall to a depth of approximately 30 feet.

3.2.10 New Outfall

The existing GWTP outfall pipe is 8 inches in diameter and used only for effluent discharge. Once the final Site cap (a separate common element described further below) is constructed, stormwater that previously infiltrated into the ground will have to be collected and discharged. Based on a 100-year storm event, the peak stormwater discharge rate was estimated at 11 cubic feet per second or 4,900 gpm. Under this common element, a new 20-inch-diameter outfall (Appendix B, **Drawings 101-CE-103 and 101-CE-104**) would be installed under Alternatives 2 through 7 to provide for stormwater discharge to Puget Sound~~Eagle Harbor~~, using horizontal directional drilling methods, at an estimated cost of $3.3 million.

3.2.11 Passive Groundwater ~~(~~Discharge/~~rainage)~~ Treatment

This common element provides technology for long-term management of the upper aquifer groundwater elevation. Under current conditions, upper aquifer water levels are controlled by operation of the hydraulic containment wells. If these wells are turned off, upper aquifer water levels would rise

Commented [YCK(13]: Below ground surface or MLLW? Same for Section 3.2.9.

potentially flooding portions of the FPA; most~~ly~~ likely during the winter and springs months when rainfall levels are highest. Flooding would likely hinder future site use.

The passive discharge/treatment system would consist of a series of drain systems that would maintain the upper aquifer groundwater elevation at a level of approximately -1 foot MLL~~S~~W. ~~post-active remediation of low-level dissolved-phase Upper Aquifer groundwater contamination, if necessary, using a passive te~~Each drain ~~chnology. This~~ system includes three main components: a collection system, a treatment media such as granular-activated carbon (GAC) housed in a utility hole-accessible vessel to remove dissolved-phase COCs, and a pipe that conveys the treated water through ~~to the discharge location outside~~ the sheet pile wall and the new concrete bulkhead (Appendix B **Drawings 101-CE-105 and 101-CE-301**) to a discharge point below the mudline.

The design concept utilizes the hydraulic head difference presents during the outgoing tide to move the water through the GAC to the discharge point. It is estimated each system would treat about 360,000 gallons of groundwater per year (3.6 million gallons total, assuming 10 systems) recovering 570 kilograms of dissolved-phase contaminant mass. The groundwater treatment volume was estimated from a tidal flux analysis described in Appendix D.

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The drain systems would be located around the perimeter of the FPA in areas where NAPL is absent and dissolved phase COC concentrations are expected to be lower. This approach may eliminate the need for treatment at some locations while reducing GAC usage at locations where treatment is required.

For the purposes of this FFS, 10 independent systems would be installed using vertical wells under Alternative 4 at an estimated cost of $1.3 million. Under Alternatives 3, 5, 6, and 7, short horizontal drains would be used ~~instead of wells~~ at an estimated cost of $1.1 million. Annual O&M costs under Alternative 4 are estimated at $333,000 and $284,000 for Alternatives, 3, 5, 6, and 7 and assume a quarterly GAC media changeout frequency.

During remedial design, and the initial phase of remedy implementation ~~phase~~, additional information will be collected to determine where treatment is required and to size the GAC vessels. This information may justify the need for fewer systems or manifolding each collection drain to a centralized treatment system with a single discharge outfall.

3.2.12 Final Site Cap

The planned final end use of the Wyckoff Site is a park with open areas. To reduce surface water infiltration at the Site and prevent exposure to potential, low-level residual contaminants, a permanent surface cap with a low-permeability geomembrane layer is included as a common element for all alternatives.

The conceptual design assumed for this FFS (Appendix B, **Drawings 200-CE-101 and 200-CE-301**) is based on a 60-mil high-density polyethylene (HDPE) geomembrane overlain by 12 inches of drainage material and 12 inches of topsoil. A 12-ounce-per-square-yard cushion geotextile would be placed over the geomembrane to provide drainage layer puncture protection. The total covered area is 8.1 acres. The drainage material and topsoil will be imported to the Site and will have a total volume of 13,050 CY each. During remedial design, the cap design could modified to support an alternate topographic profile if desired. The estimated cost for this common element is $4.1 million.

3.2.13 Long-term Monitoring~~Monitored Natural Attenuation~~

~~Monitored natural attenuation (MNA) relies on natural degradation and nondegradation processes to decrease contaminant concentrations. When relying on MNA processes for site remediation, EPA prefers processes that degrade or destroy contaminants (EPA, 1999). The key degradation processes for dissolved-phase creosote constituents at the Wyckoff Site include aerobic and anaerobic~~

~~biodegradation. The key nondegradation processes include dispersion and groundwater-surface water mixing.~~

~~Under current Site conditions, anaerobic biodegradation is expected to be the most important MNA process for the LPAHs. Based on information provided in *Anaerobic Biodegradations for Organic Chemicals in Groundwater: A Summary of Field and Laboratory Studies* (EPA, 1999), it is estimated that 1,381 kilograms per year of naphthalene are biodegraded based on a half-life of 258 days.~~

Under this common element, a network of existing monitoring wells would be sampled quarterly to track Upper Aquifer remediation accomplishments, while Lower Aquifer wells would be sampled annually to confirm that no further degradation is occurring per RAO #4~~assess MNA rates~~. This common element is a recurring item at annual O&M cost under Alternatives 2 through 7 of approximately $90,000 per year.

3.2.14 Access Controls

For all remedial alternatives (except Alternative 1—No Action), Site fencing would remain until the Site could be converted to a public area. ICs to ensure that the Upper Aquifer groundwater within the FPA remains unused would be maintained. ICs restricting Site use to reduce direct exposure to soil would also be maintained. No capital or annual O&M cost has been assumed for this common element.

3.2.15 5-Year Reviews

The NCP, under 40 CFR 300.430(f)(4) (ii), requires that periodic reviews be conducted if a remedial action is selected that results in hazardous substances, pollutants, or contaminants remaining at the Site above levels that allow for unlimited use and unrestricted exposure. These reviews are conducted no less often than every 5 years after the selected remedial action is initiated. Three 5-year reviews have been performed to date, with the third 5-year review completed in 2012. This common element provides for continuing the 5-year reviews until the contaminants are no longer present at unrestricted use and/or unrestricted exposure levels. For this FFS, a 5 year, $20,000 periodic cost was include for each alternative.

3.3 Description and Screening of Remedial Alternatives

This section describes the seven NAPL source area remedial action alternatives listed in Section 3.1. Each description includes a narrative summary of the key components, a table listing the primary components, and engineering drawings showing equipment layout, treatment diagrams, and implementation logic. All drawings referenced in this section are provided in **Appendix B** and the cost estimates presented in **Appendix C**.

3.3.1 Alternative 1—No Action

Section 300.430(e)(6) of the NCP requires that a No Action Alternative be included in the FFS to use as a baseline for comparison to other alternatives. Under Alternative 1—No Action, no additional actions would be taken for the Wyckoff Soil and Groundwater OUs. The existing groundwater extraction wells and GWTP would be shutdown (if operating), and this equipment would not be decommissioned. The outer sheet pile wall would be left in place, and over time, it would be expected to fail near the mudline due to corrosion. The sections of wall present below the mudline may still provide some partial containment of NAPL and dissolved-phase contaminants.

3.3.1.1 Screening Evaluation

Per the NCP (40 CFR 300.430) requirement to develop the No Action Alternative and carry it through the detailed analysis of alternatives, Alternative 1—No Action was not screened and will be retained.

3.3.1.2 Cost Estimate

Alternative 1 has no components, and therefore, the net present value cost is $0.

3.3.2 Alternative 2—Containment

Alternative 2 is the contingent remedy implemented under the 2000 ROD. Including this alternative in the FFS satisfies the NCP requirement to develop an alternative that involves little or no treatment and protects human health and the environment by preventing or controlling exposure to contaminants through engineering controls and, as necessary, ICs.

Under this alternative, constructing the remaining containment components specified in the 2000 ROD would be completed, and the remedy operated for 100 years. The key components of Alternative 2 include the following (**Table 3-3**):

- The applicable common elements listed in **Table 3-2**.
- An outer sheet pile wall that is 1,870 feet long bounding the north and east sides of the FPA. This remedy component was installed in 2001. It is assumed that the wall would be replaced once during the 100-year O&M timeframe.
- Installation of four new recovery wells and rehabilitation of the nine existing recovery wells (Appendix B **Drawing 200-C-100**). All wells would be completed with flush-mounted vaults and buried HDPE piping. The total system pumping rate with all 13 wells in operation would vary seasonally from 80 to 140 gpm. The wells would operate 24 hours a day, 7 days a week, except for maintenance and repair and during electrical service disruptions.
- Upgrades to the existing GWTP electrical and instrumentation and control systems to provide greater remote/off-Site wellfield and GWTP operations control and improved reliability.
- One hundred years of O&M. The recovery wells and some GWTP mechanical equipment are assumed to require replacement approximately every 30 years. GWTP tanks and piping constructed of fiberglass reinforced plastic would not need replacement due the integrity of this material.
- Periodic sampling and analysis to accomplish the following: 1) confirm GWTP treatment effectiveness, assess the need for treatment media changeout, and compliance with outfall discharge criteria, 2) assess COC concentration changes in Upper and Lower Aquifer groundwater, and 3) verify hydraulic containment of the dissolved-phase plume.
- Existing engineering controls (GWTP and recovery well fencing and signage) and ICs would be maintained to prevent unauthorized land and groundwater use and to protect the integrity of the soil cover.
- Documentation of remedy performance and protectiveness in 5-year reviews.

The location of the four new and nine existing recovery wells is shown on Appendix B, **Drawing 200-C-100**. A process flow diagram showing the various treatment steps in the existing GWTP is shown on Appendix B, **Drawing 200-CE-102**.

Under this alternative, hydraulic containment pumping would remove an estimated 737 kilograms of dissolved-phase COCs per year~~, while natural attenuation would biodegrade an estimated 1,381 kilograms[3] of dissolved-phase COCs per year~~. Pumping the hydraulic containment wells would also

~~[3] This estimate may be revised following completion of Appendix D.~~

remove DNAPL with recovery rates steadily declining from an estimated 4,000~~3,972~~ gallons per year in 2016 to 100~~28~~ gallons per year by ~~in~~ 2116. Based on the 100-year O&M timeframe established for this alternative, it is estimated that ?~~53~~ percent of the NAPL present in the Upper Aquifer~~FPA~~ would be removed.

Alternative 2 addresses RAO #1 by installing a final Site cap across the FPA to prevent direct contact with contaminated soil and maintaining ICs to protect cap integrity and to prevent inadvertent intrusion through the cap to the underlying contaminated soil. RAO #2 is addressed by implementing and maintaining ICs that prevent Upper Aquifer groundwater withdrawals except for remediation purposes. Engineering controls (fencing and signage) would also be maintained around the GWTP and extraction well vaults to prevent potential contact with contaminated groundwater pumping equipment. RAO #3 is addressed by operating the recovery wells to hydraulically contain the dissolved-phase plume, thereby preventing migration to Eagle Harbor and Puget Sound, and treating Upper Aquifer groundwater in the GWTP prior to Eagle Harbor outfall discharge. RAO #4 is addressed by operating the Upper Aquifer hydraulic containment system to maintain an upward vertical gradient thereby preventing dissolved phase ~~and MNA within the Lower Aquifer to reduce~~ COC transporting from the Upper Aquifer ~~concentrations~~ to the Lower Aquifer~~ groundwater PRGs~~.

3.3.2.1 Implementation and Sequencing

The general sequence and duration of key activities under Alternative 2, assuming all elements of the alternative were fully funded, would include the following:

Year 0 - 1	Year 2	Year 3 - 100	ear 100
• Construct common elements • GWTP O&M	• Complete common elements construction (final cap) • New recovery well installation and rehab of existing wells	• GWTP O&M	• GWTP decommissioning

3.3.2.2 Screening Evaluation

Screening of Alternative 2—Containment against the criteria of effectiveness, implementability, and cost indicates that this alternative should be retained. This alternative would be effective because it reduces or eliminates contaminant migration through treatment and over the long term also reduces toxicity and volume. This alternative would be readily implemented because most components have already been constructed. Although long-term O&M costs are expected to be high, some of this cost would be offset by low capital costs.

3.3.2.3 Cost Estimate

The total present worth cost for Alternative 2, based on a 1.4 percent discount rate, is $79~~0~~.8~~6~~ million with a -30/+50 percent cost range of $55.9~~49.4~~ million to $119.7~~05.9~~ million. A breakout of total life cycle costs is provided in **Table 3-3**.

3.3.3 Alternative 3—Excavation, Thermal Desorption, and In Situ Chemical Oxidation

Alternative 3 addresses the NCP requirement to develop an alternative that removes contaminants to the maximum extent practicable minimizing the need for long-term management. This alternative includes the following components:

- The applicable common elements listed in **Table 3-2**.
- Excavation and thermal desorption treatment of contaminated soil present in the Core Area, North Shallow (LNAPL), and East Shallow (LNAPL) target zones. The design basis for this alternative assumes a medium temperature thermal desorption (MTTD) unit operating at a rate of 20 tons per hour. Assuming soil excavation is conducted 50 hours per week, and the MTTD unit operates 100 hours per week, 1,500 CY of contaminated soil would be treated per week.
- ISCO-permanganate treatment of NAPL-contaminated material present in the North Deep (DNAPL) target zone. Three separate injection events would be performed with groundwater monitoring conducted following each injection event. The monitoring results would be used to confirm treatment effectiveness and to optimize the scope of subsequent injection events.
- ISCO-hydrogen peroxide treatment of small amounts of NAPL-contaminated material present in the Other Periphery target zone. ISCO-hydrogen peroxide treatment would be applied in a manner similar to that described above for ISCO-permanganate treatment.
- Enhanced aerobic biodegradation (EAB) following completion of Core Area, North Shallow (LNAPL), and East Shallow (LNAPL) treatment using an array of biosparge wells that would inject air into the Upper Aquifer.

The excavation, MTTD, and ISCO treatment steps would be performed simultaneously. EAB would be implemented after the excavation, MTTD, and ISCO treatment steps. Additional information on the primary alternative components of excavation, MTTD, and ISCO is provided in the subsections below.

This alternative addresses RAOs #1 through #3 by excavating and thermally treating NAPL-contaminated soil to destroy ~~reduce~~ COC~~ concentration~~s and installing a final cap to serve as a barrier to direct contact ~~to the defined PRGs~~. The ISCO treatment program, is designed to achieve a high level of treatment but it's uncertain that ISCO treatment alone would achieve the soil and Upper Aquifer groundwater PRGs; therefore, EAB would be implemented to complete any remaining treatment necessary to achieve Upper Aquifer groundwater PRGs. RAO #4 is addressed through treatment of Upper Aquifer NAPL source material thereby preventing the formation and transport of dissolved phase contaminants to ~~and MNA within~~ the Lower Aquifer~~ to reduce COC concentrations to the Lower Aquifer groundwater PRGs~~.

3.3.3.1 Excavation Methods

In the Core Area, the target depth interval for excavation and thermal desorption would include the ground surface down to the top of the Aquitard (i.e.~~g.~~, Compartments 1, 2, and 3). In the North Shallow (LNAPL) and East Shallow (LNAPL) target zones, excavation would extend to an estimated depth of 35 feet bgs. The footprint for each target zone would be subdivided into an array of excavation cells, and each cell geotechnically and hydraulically isolated by internal and external braced sheet pile walls. After the sheet pile walls are installed, the excavation cell would be dewatered using two dewatering wells and the water pumped to the existing GWTP for treatment. Excavation would proceed downward in vertical lifts until the target depth is reached. As each excavation cell is completed, treated soil would be returned to the excavation and used for backfilling. Once the Core Area excavation cells are completed, the work would proceed to the North Shallow (LNAPL) and East Shallow (LNAPL) target zones.

Excavation of the North Shallow (LNAPL) and East Shallow (LNAPL) target zones would be performed in a similar manner but would not requiring lowering of the water table to the same degree as the Core Area due to the shallower excavation depths.

3.3.3.2 Thermal Desorption Treatment

Excavated soil would be treated through a direct-fired thermal desorption unit that includes a rotary desorber for soil treatment, a baghouse for dust collection, and a thermal oxidizer to destroy organic vapors. Excavated material would be segregated in stockpiles for air drying and subsequent loading into the thermal desorber unit. A burner located at the discharge end of the desorber unit would provide the energy to heat the soil, causing organic compounds to volatilize into an air stream and be carried out of the unit. Material processing temperatures would be adjusted during the treatment process based upon COC concentrations present in the feed stockpile and soil PRGs. For this FFS, a soil temperature of 1,100 degrees Fahrenheit (°F) is assumed. Field-scale trials would be conducted to establish optimum treatment temperatures and contact times. After treatment, the soils would exit the kiln at temperatures of 400 to 900 °F and be staged for cooling and confirmation testing prior to placement as backfill in the excavation cells.

Air containing water, organic vapors, and particulate matter would exit the desorber unit to the baghouse, where particulates would be removed. The resulting air flow would be routed to the thermal oxidizer and heated to between 1,400 and 1,800 °F, at which point the organics would be combusted to carbon dioxide and water vapor. The creosote NAPL present at the Wyckoff Site contains PCP, which would generate hydrochloric acid in the thermal oxidizer unit. Therefore, the offgas would undergo additional treatment in an acid scrubber or thermal oxidizer unit operations limited per hydrochloric acid atmospheric discharge regulatory limits. Air monitoring of the thermal oxidation unit would be performed to confirm that the stack offgas complies with discharge limits.

3.3.3.3 In Situ Chemical Oxidation Treatment

The North Deep (DNAPL) target zone would be treated using ISCO-permanganate with treatment occurring in Compartment 3. Permanganate was selected because of the depth of DNAPL contamination lying below the water table, its effectiveness for PAH treatment, the persistence of its oxidizing power, and its relative ease of injection through temporary or fixed wells. The primary disadvantage of permanganate is its potential negative impact on groundwater quality (e.g., increased manganese concentrations and discoloration) and the conditions required to apply EAB polishing. A lag period would exist before suitable conditions for EAB are reestablished.

To reduce the overall oxidant demand and increase ISCO treatment effectiveness, a program of enhanced NAPL recovery from existing and newly installed recovery wells would precede ISCO injection. Once the enhanced NAPL recovery step is completed, oxidant injection would be performed through the same wells used for enhanced NAPL recovery. Following completion of the initial (Phase 1) permanganate injections, which are expected to require about 6 months, changes in PAH concentration, redox conditions, and other groundwater quality parameters would be monitored for 6 to 12 months. Reductions in hydraulic conductivity from precipitated manganese dioxide, which could decrease future injection rates, would also be assessed. Following the Phase 1 injection and monitoring period, Phase 2 injections would occur. The Phase 2 injections are assumed to require approximately 50 percent of the permanganate mass injected during Phase 1. After the Phase 2 monitoring period is completed, Phase 3 permanganate injection would occur. Phase 3 injections are assumed to require approximately 25 percent of the permanganate mass injected during Phase 1.

In the Other Periphery target zone, ISCO would be implemented with catalyzed hydrogen peroxide injected through direct-push technology to provide more focused treatment. Up to three ISCO injections, performed in a phased manner, are assumed to be required in a similar manner as described above for the permanganate injection in the North Deep (DNAPL) target zone.

For both oxidant types, Site-specific, bench-scale testing of oxidant dosage in both Upper Aquifer and Aquitard material would be performed along with field-scale pilot tests during remedial design to confirm treatment effectiveness prior to full-scale field deployment.

3.3.3.4 Screening Evaluation

Screening of Alternative 3—Excavation MTTD and ISCO against the criteria of effectiveness, implementability, and cost indicates that this alternative should be eliminated based on implementation considerations. During preliminary engineering, the degree of shoring and dewatering necessary to excavate Upper Aquifer soil to depths up to 55 feet bgs was determined to not be technically practicable without incurring significant geotechnical risk. Additionally, due to these considerations, it was apparent that the cost of this alternative would be grossly excessive relative to its effectiveness.

3.3.3.5 Cost Estimate

Because this alternative was eliminated at the screening step, a cost estimate was not prepared.

3.3.4 Alternative 4—In Situ ~~Stabilization/Solidification~~Solidification/Stabilization

Alternative 4 addresses the NCP requirement to develop an~~d~~ alternative that treats the principal threat posed by the Site but varies in the degree of treatment and the characteristics of the treatment residuals. Under Alternative 4, all NAPL-contaminated material greater than the TarGOST 10% RE would be treated in situ by immobilizing the NAPL in a cement~~-~~-type matrix. This approach is expected to greatly reduce the need for long-term management. Alternative 4 includes the following components (**Table 3-4**):

- Each of the applicable common elements listed in **Table 3-2**.
- ISS of NAPL-contaminated material using a combination of auger mixing and jet grout techniques in each of the five remedial action target zones as follows:
  - **Core Zone—**85,300 CY of contaminated material would be treated to a depth of about 50 feet.
  - **North Shallow (LNAPL)—**17,700 CY of contaminated material would be treated to a depths ranging from 25 to 45 feet
  - **North Deep (DNAPL)—**About 59,200 CY of contaminated material would be treated to depths up to 76 feet (treatment in this area includes auger mixing of more shallow impacts and jet grout mixing of discreet deeper zones of impacts)
  - **East Shallow (LNAPL)—**120,000 CY of contaminated material would be treated to depths ranging from 25 to 45 feet
  - **Other Periphery—**43,100 CY of contaminated material would be treated to a depth ranging from 10 to 45 feet
- The overall approach as presented in the following subsections assumes that ISS would be performed 10 hours per day, 7 days per week, requiring approximately 2 years. ISS is assumed to have a ?~~100~~ percent treatment efficiency, because the technology promotes excellent contact between the reagent and the NAPL-contaminated material.
- An additional 2,700 CY of soil would receive ISS treatment along the bulkhead to solidify soil to a minimum elevation of -15 MLLW to facilitate repairs and new wall construction
- Excavating and removing 7 feet (86,000 CY) of overburden material to offset the swell that occurs during ISS treatment. Excavated material would be staged and treated in an aboveground treatment

cell using ISS reagent and the material reused for final Site grading and contouring. Groundwater and stormwater that accumulates in the excavation would be pumped to the GWTP for treatment and outfall discharge. Berms and trenches would also be used to minimize stormwater entry into the excavation footprint.

Under Alternative 4, an estimated ?~~95~~ percent of 678,000 gallons of the NAPL present in the FPA would be immobilized. The remaining ?~~5~~ percent would be addressed through natural attenuation and passive groundwater treatment.

This alternative addresses RAOs #1 through #3 by altering NAPL characteristics to reduce toxicity, mobility, and leachability, thereby protecting human health from unacceptable risk due to direct contact and protecting the environment by eliminating a dissolved-phase contaminant source. RAO #4 is addressed through solidification and stabilization ~~treatment~~ of Upper Aquifer NAPL source material thereby significantly reducing the leaching of COCs at levels that would degrade ~~and MNA within the~~ Lower Aquifer potable groundwater ~~to reduce COC concentrations to the Lower Aquifer groundwater to PRGs~~.

3.3.4.1 In Situ ~~Stabilization/Solidification~~Solidification/Stabilization Description

Auger mix ISS would be performed using a crane mounted auger or hydraulic drill rig. For deep soil application (60 to 75 feet bgs) in the North Deep (DNAPL) zone, small diameter, jet grout injection equipment would be used. One~~Two~~ ISS auger rig~~s~~ would operate at the Site full-time. Appendix B, **Drawing 300-C-100** shows the ISS Site layout and **Drawings 300-C-101, 300-C-102 and 300-C-103** show the footprint where auger ISS, jet grout ISS an ex~~s~~ situ ISS would be implemented, respectively.

In the Core Area, North Shallow (LNAPL), East Shallow (LNAPL), and Other Periphery target zones, the ISS auger rigs would mechanically mix reagent and NAPL-contaminated soil, creating an array of overlapping, cement-like columns extending from the surface to the bottom of the target zone. Reagent for the ISS would be delivered to the Site by truck and mixed on Site in a batch plant.

In the North Deep (DNAPL) target zone, jet grouting equipment would be used to mix the reagent and NAPL-contaminated soil. Due to the high pressures employed for jet grouting, the reagent and NAPL-contaminated soil are fluidized rather than mechanically mixed. Jet grouting ISS would also ~~would~~ create an array of overlapping, cement-like columns, but the columns would be ~~generally~~ smaller in diameter than those created with vertical augers.

~~Areas of the Site would be treated with both auger-mix ISS and jet grouting, with untreated zones between as shown on Appendix B, **Drawing 300-C-300**.~~ Along the perimeter of the ISS treatment zone, the mix design would be enriched to create a “rind” or ”crust” to form a contiguous ring of overlapping columns with increased durability and leaching resistance achieved ~~resulting~~ from a higher unconfined compressive strength performance requirement. This crust is shown on **Drawing 300-C-103**.

Prior to commencing ISS, the treatment area would be excavated to a depth of 7 feet to create a sump to contain the swell volume that accompanies ISS. This volume expansion is estimated to range from 20 to 25 percent of the ~~original~~ treatment volume. The excavated material would be treated in an aboveground cell (**Drawing 300-C-100**) using the ISS reagent and stockpiled for future Site grading and contouring reuse.

3.3.4.2 Design Criteria and Basis for Approach

Following are the primary ISS design criteria:

- Identify the compressive strength for the stabilized material that supports future Site reuse.
- Determine the leaching reduction needed to achieve ~~soil and~~ Upper Aquifer groundwater PRGs.

- Develop mix design for inner and perimeter columns. The mix design for the perimeter columns is expected to contain a higher concentration of reagent relative to the inner columns to improve durability characteristics.
- Conduct Upper Aquifer groundwater flow modeling to evaluate: 1) altered ~~new~~ groundwater flow patterns around and beneath the ISS monolith, 2) ~~evaluate~~ groundwater elevation mounding that could result in groundwater seeps, and 3) ~~to estimate~~ post ISS groundwater quality conditions.

Bench-scale testing would be performed during remedial design to determine the optimum reagents, mix ratios, and reagent addition rates for the inner and perimeter columns. The mix design would be evaluated by measuring the maximum hydraulic conductivity, minimum unconfined compressive strength, and overall leaching reduction in a series of tests prepared using NAPL-contaminated soil obtained from the Site. The bench-scale testing would also include o~~O~~ptimization testing to ~~may also be performed to better~~ refine the reagent mix design, establish ranges for reagent and water addition ratios, and evaluate reagent enhancements that can be added to improve performance (e.g., decrease leachability) or lower costs. For the purposes of this FFS, and b~~B~~ased on experience at other wood-treating Superfund sites (e.g., Mountain Pine, North Cavalcade, ~~and~~ Texarkana, and American Creosote Works), the mix design for Alternative 4 may include~~s~~ up to 10 percent Portland cement and 1 percent bentonite. A typical compressive strength of 50 pounds per square inch (psi) with no single point less than 40 psi is assumed for this FF~~S~~S. Compressive strength is an indirect indicator of durability as materials with higher initial compressive strength are typically considered more resistant to aging (Interstate Technology and Regulatory Council [ITRC], 2011). For the perimeter crust, the target compressive strength would be double the requirement of the interior columns or a minimum of 100 psi.

A field demonstration test would also be performed to verify the bench-scale results, evaluate full-scale equipment options, establish productivity rates, and identify Sitewide implementation considerations. Due to logistical limitations associated with mobilizing ISS equipment to the Site for a field scale pilot test, a demonstration test would occur at the start of full-scale remediation.

Contaminant l~~L~~eaching is reduced by either a reduction in hydraulic conductivity or by using amendments to absorb organic constituents. The lower hydraulic conductivity of the ISS monolith relative to the surrounding soils forces groundwater around it, thereby reducing the potential for groundwater to come into direct contact with entombed COCs. Absorbents (activated carbon or oleophilic clay) can reduce leaching by increasing the ability to absorb contaminants over native soils. B~~However, b~~ased on testing conducted for other CERCLA NAPL contaminated sites the increased cost of absorbent may ~~does~~ not warrant the nominal decrease ~~increase~~ in leachability that is typically observed~~performance~~. For this FFS, an absorbent material is assumed to not be necessary.

Leaching reduction would be evaluated through treatability testing conducted during remedial design to aide in selecting the most effective reagent mix design. Leachability testing would be conducted on both the untreated NAPL-contaminated soil and the NAPL-contaminated soil treated with various mix designs after a 28-day cure period. The test would be conducted in accordance with the approaches presented in the *Development of Performance Specifications for Solidification/Stabilization* (ITRC, 2011) using EPA pre-methods known as Leaching Environmental Assessment Framework. The leaching characteristics of the untreated material would be evaluated using Pre-method 1314 or 1316, while the treated material would be evaluated using Pre-method 1315 to assess the reduction in leaching after treatment. These tests are not intended as a measure of performance during full-scale ISS, but rather as a tool to identify the most effective mix design and to provide data to model post-ISS groundwater quality conditions outside the target zones.

3.3.4.3 Implementation and Sequencing

Given the Site's size and volume of material to be treated, several operations would be performed concurrently. Field activities would generally be sequenced as shown on Appendix B, **Drawing 300-C-301 and 300-C-600,** as follows:

1. The ISS auger rig and reagent batch plant would first be mobilized and set up~~-~~. Large items such as silos and the ISS auger rig would be transported to the Site via barge and ~~crane and~~ offloaded via crane over the existing sheet pile wall. Smaller items that can be transported without oversize load restrictions would be delivered to the Site via truck. The batch plant would be set up in a central location to allow for delivery of reagent to the entire treatment area. In general, the batch plant must be located within 1,000 feet of the target zones. Additional grading surface stabilization may be required within the batch plant and bulk material storage area. The batch plant includes pumps, mixers, silos, mixed reagent storage, tool shed, and laydown areas. ISS operation likely would be performed year-round; as such, adequate winterizing of the batch plant would be required.
2. Site controls, erosion and sediment controls, stormwater controls and collection systems, odor and vapor controls systems, temporary facilities, and temporary utilities would be installed. Perimeter air monitoring systems would be set up prior to the start of subsurface intrusion activities.
3. As the swell sump excavation progresses from north to south across the Site, jet grouting would be initiated in the North Deep (DNAPL) target zone. Prior to full-scale jet grout treatment, a jet grout field demonstration test would be performed to evaluate jet grout characteristics and expected jet grout column size based on the Site-specific conditions. Several columns would be created using varying injection pressures, drill stem revolutions per minute, and drill stem withdrawal rate. The columns would be created at a depth that allows for excavation and observation after curing. Jet grouting would occur prior to auger mix ISS in areas that are treated using both techniques to avoid drilling through previously solidified soils.
4. As the swell sump excavation and jet grout ISS operations proceed south across the Site, ISS auger mixing would begin. Mixing would be accomplished with 6-foot- and 8-foot-diameter augers, depending on required depth of treatment and mixing difficulty. While auger diameter up to 10 or 12 feet are often used for large ISS projects, smaller diameter augers may be required to penetrate and mix "hard" soil layers. A review of the existing boring logs in the FPA indicates the presence of varying thickness of poorly and well-graded sand and gravel. Standard penetration test "blow counts" ranged from 35 to 55 blows per foot using a 300-pound hammer. This soil density would slow auger advancement requiring more mix time and potentially the addition of more reagent. Using smaller-diameter augers would improve mixing conditions and minimize auger refusal. ISS columns would be overlapped to treat 100 percent of the NAPL-contaminated soil within the target zone. The first several days would be used to demonstrate that the treatability results are verified and to establish the effectiveness of the selected equipment to mix sufficiently to the target depths. Visual observations, field tests, and quick turnaround laboratory testing would be used to demonstrate achievement of performance requirements.
5. Quality control during full-scale ISS includes the following:
    a. Verifying contractor calculations for reagent slurry mixture and for volume of reagents to be added for each ISS column.
    b. Requiring the contractor to complete at least three mixing strokes (a stroke is from top to bottom to top again).

c. Discrete sampling at different depth intervals to check for consistency of mixing, using color charts, pH, and slump. No unmixed soil should be observed in the sample. This sampling would be done at no less than one time per shift.

d. Collection of samples for laboratory testing at a frequency of once every 500 CY or once per shift, whichever is less. This frequency would be reduced once data shows that the contractor can consistently meet performance requirements after the completion of 10,000 CY or 20 days of mixing.

6. Stockpiled soil removed during the sump excavation step would be treated using ex situ solidification/stabilization. A treatment cell(s) would be created using a lined and bermed area. Measured quantities of soil would be transferred from the soil stockpile to the treatment cell and mixed with reagents. The same reagent mix design used for ISS is assumed to be appropriate to treat the preexcavation soils, although the water ratio may be adjusted for ex situ conditions. This would be evaluated during the initial demonstration period. The soil and reagent mixture would be mixed using a hydraulic excavator and/or excavator equipped with a horizontal blending attachment. When the soil is adequately mixed, it would then be transferred on Site and allowed to cure in place for final Site grading and contouring, consistent with planned future Site use, to create landscape features.

7. At completion of ISS, the contractor would decontaminate equipment, dismantle the ISS auger and jet grout rig and batch plant, and demobilize.

8. The passive groundwater treatment system and final soil cap would be installed after ISS demobilization.

Groundwater monitoring performed following completion of ISS treatment would be used to confirm groundwater flow patterns and assess the need for the passive groundwater treatment common element.

The general sequence and duration of key Alternative 4 elements, assuming all elements of Alternative 4 were fully funded, would include:

Year 0	Year 1	Year 2	Year 3 - 10
• Construct common elements • GWTP O&M	• Construct common elements • Plug and abandon recovery/monitor wells within the ISS footprint • Complete auger and jet grout ISS	• Passive groundwater discharge/treatment system construction • Final site cap construction • GWTP O&M	• Passive groundwater discharge/treatment O&M • GWTP decommissioning

3.3.4.4 Screening Evaluation

Screening of Alternative 4—ISS against the criteria of effectiveness, implementability, and cost indicates that this alternative should be retained. This alternative would be effective because it would reduce NAPL toxicity and mobility through treatment, achieve protection in a relatively short timeframe, and minimize the need for long-term management. ISS treatment of NAPL contaminated material will significantly alter the Upper Aquifer's hydrogeologic characteristics. The reduction in hydraulic conductivity within the ISS monolith will change groundwater flow patterns diverting flow from the upgradient portion of the FPA around or beneath the ISS monolith. With the perimeter sheet pile wall blocking natural groundwater discharge to Eagle Harbor and Puget Sound, the passive groundwater discharge/treatment systems will be an important long-term water balance management tool.

This alternative would be readily implemented using technology and equipment proven at other NAPL-contaminated sites, although some implementation elements would need to be refined during the field demonstration. ISS deployment using auger mixing has been successfully implemented at a number of hazardous waste sites, however, the depth and volume of material to be treated at this site would make this one of the largest ISS projects implemented. Jet grouting technology to improve soil geotechnical properties is also a mature technology. The deployment of ISS technology at the site may pose some implementation challenges due to the depth of treatment, dense nature of aquifer materials, and potential presence of subsurface fill debris placed during site development. Jet grouting has been successfully used at the Department of Energy's Hanford site to distribute pre-formed apatite in the Hanford formation, which is comprised of a dense mixture of cobbles, gravel and sand. Although this use occurred at shallow depths (25 feet), it demonstrates that the technology can successfully fluidize large coarse-grained material.

While the cost would be high, due the volume and depth of NAPL-contaminated material requiring treatment, this cost is not disproportionate to overall effectiveness.

3.3.4.5 Cost Estimate

The total present worth cost for Alternative 4, based on a 1.4 percent discount rate, is $93~~86~~.7~~3~~ million with a -30/+50 percent cost range of $65~~0~~.6~~4~~ million to $140~~37~~.6~~1~~ million. A breakout of total life cycle costs is provided in **Table 3-4**.

3.3.5 ~~-~~Alternative 5—Thermal Enhanced Extraction and In Situ ~~Stablization/Solidification~~Solidification/Stabilization

Alternative 5 addresses the NCP requirement to treat the principal threats posed by the Site using thermal enhanced extraction to draw NAPL from the subsurface in the Core, North Shallow (LNAPL), and East Shallow (LNAPL) zones and destroying the NAPL in an aboveground thermal oxidation unit. In the North Deep (DNAPL) zone, NAPL is immobilized using ISS. Alternative 5 includes the following components (**Table 3-5a**):

- Each of the applicable common elements listed in **Table 3-2**.
- Enhanced NAPL recovery using an array of multipurpose wells and the GWTP for approximately 3 years. Mobile NAPL removal prior would shorten the duration of the thermal treatment period thereby reducing cost.
- Thermal steam-enhanced extraction and thermal destruction of NAPL as follows:
  - **Core Zone—**186,000 CY of contaminated material would be treated to a depth of about 55 feet.
  - **North Shallow (LNAPL) zone—**18,600 CY of contaminated material would be treated to depths ranging from 25 to 45 feet.
  - **East Shallow (LNAPL) zone—**143,000 CY of contaminated material would be treated to depths ranging from 25 to 45 feet.
- ISS of the North Deep (DNAPL) zone. 29,400 CY of contaminated material would be treated to depths up to 76 feet using the jet-grout mixing as described for Alternative 4.
- EAB[4] of the Other Periphery zone. 327,000 CY of low-level NAPL-contaminated material present at depths from 10 to 45 feet would be treated.

[4] EAB may also be referred to as biosparging in the text and Appendix B drawings.

- EAB polishing of thermally treated zones. After thermal treatment is completed, EAB would be implemented in each zone as a polishing step to promote aerobic biodegradation of residual NAPL and dissolved/sorbed-phase COCs. Residual heat from the thermal treatment step would accelerate aerobic biodegradation promoting a higher degree of treatment.

Under this alternative, the enhanced NAPL recovery (?~~26~~ percent), thermal enhanced extraction (?~~52~~ percent), and EAB (?~~8~~ percent) technology pairing would remove and destroy an estimated ?~~86~~ percent of the NAPL present in the FPA, while ISS would immobilize ?~~12~~ percent. The remaining ?~~2~~ percent would be treated through natural attenuation processes (?~~1~~ percent) and passive groundwater treatment (?~~1~~ percent).

This alternative addresses RAOs #1 through #3 using multiple technologies to extract, destroy, and immobilize NAPL source material thereby reducing COC concentrations in Upper Aquifer soil and groundwater to levels that would allow for further concentration reductions to PRGs through EAB treatment. RAO #4 is addressed through treatment of Upper Aquifer NAPL source material to reduce COC concentrations to levels that prevent further degradation of ~~and MNA within the Lower Aquifer to reduce COC concentrations to PRGs in~~ Lower Aquifer potable groundwater.

3.3.5.1 Enhanced NAPL Recovery Description

Thermal treatment would be preceded by a period of enhanced NAPL recovery from an array of 147 extraction wells (Appendix B **Drawing 400 C-100**). NAPL and groundwater would be extracted using pneumatically driven pumps. The wells and pumps are both compatible with thermal-steam injection operations. Enhanced NAPL recovery reduces the duration and cost of the steam-injection phase. During the initial phases of recovery, NAPL and groundwater would be pumped directly from the wells. As NAPL recovery volumes diminish, NAPL recovery would be enhanced by increasing the gradient through injection of treated water from the GWTP. During the NAPL recovery phase, the Upper Aquifer recovery wells would continue to maintain hydraulic containment of the dissolved-phase plume.

Extracted NAPL and groundwater would be pumped to the GWTP where the NAPL would be separated in a newly installed oil-water separator and the groundwater treated in the existing GWTP. Recovered NAPL would be transported and disposed of (incinerated) off Site. The total volume of NAPL recovered during the 3-year enhanced recovery program is estimated at 134,000 gallons.

3.3.5.2 Thermal Treatment Description

Thermal enhanced extraction would be performed using steam injected into an array of multi-purpose wells. The Core Area (three cells identified as Core A, Core B, and Core C) and East Shallow (LNAPL) (two cells identified as North and South) target zones would be divided into smaller treatment cells using sheet pile walls that extend from the ground surface to the top of the Aquitard so that hydraulic containment can be maintained during the thermal treatment step. To maintain hydraulic containment, the steam injection rate must be offset by a groundwater extraction rate that is equal or greater. The sheet pile walls would reduce groundwater intrusion and allow the water table to be lowered close to the bottom of the NAPL treatment zone. The total volume of NAPL-contaminated material that is thermally treated would be larger than described for Alternatives 3 and 4 to allow for “squaring off” the individual treatment cells. For example, the Core Area was extended northward in “Core C” to capture additional highly NAPL-impacted soil.

After isolating each treatment cell with the vertical sheet pile walls, a vapor barrier would be constructed over the treatment area. The vapor barrier would span 6 acres extending approximately 20 feet beyond the edges of the thermal treatment footprint (Appendix B **Drawing 400-C-101**).

After installing the vapor barrier, all remaining wells would be installed, including 27 dewatering wells, 172 multipurpose steam injection/EAB wells, 201 temperature monitoring wells, and 31 EAB wells. The 147 wells previously installed for NAPL recovery would be re-purposed as steam extraction wells. Installation of piping, fittings, instrumentation, and surface process systems would be performed sequentially and precede initiation of thermal operations in each treatment cell. After all the wells are installed, and during enhanced NAPL recovery operations, the surface process components necessary for vapor and liquid treatment would be constructed.

Core Area, East Shallow (LNAPL), and North Shallow (LNAPL)

Thermal enhanced extraction in these three areas utilizes the enhanced NAPL recovery wells for fluid/vapor extraction and injects steam through a network of injection wells installed in a repeated 7-spot configuration with a 30-foot spacing between injection and extraction wells. The layout of the 172 steam injection wells is shown on Appendix B, **Drawing 400-C-101**. The 7-spot well pattern was modified based on the placement of the sheet pile walls and identified areas of NAPL accumulation. **Drawing 400-C-101** also shows the approximate location of 201 temperature monitoring wells. The thermal treatment areas are overlain by a temporary vapor barrier to prevent steam and contaminant vapor escape and heat losses to the atmosphere during operations. This vapor barrier is augmented by active extraction of vapors through perforated piping installed under a geomembrane and/or injection of air through other piping installed under the geomembrane. Injected air is intended for extraction by the deeper, vertical steam extraction wells. The extent of the vapor barrier cap across the Core, East Shallow (LNAPL), and North Shallow (LNAPL) areas, and the placement of shallow, horizontal piping beneath the vapor barrier is shown on Appendix B, **Drawing 400-C-102**.

As NAPL recovery in the Core Area diminishes or ceases, sequential application of thermal enhanced extraction is initiated with Core A treated first, followed by Core B, and Core C. Upon completion of all thermal treatment in the Core Area, the process is moved to the East Shallow (LNAPL) South and then the East Shallow (LNAPL) North treatment cells. The North Shallow (LNAPL) target zone would be treated last.

3.3.5.3 EAB Description

After thermal operations are completed, EAB would be implemented across the thermally treated areas for approximately 1 year accompanied by hydraulic containment to promote mixing and oxygen distribution. Appendix B, **Drawing 400-C-103,** presents the biosparging well layout. EAB has synergy with the thermal treatment. Air injection for aerobic biodegradation promotes mixing dissolved contaminant mass with oxygen, while the residual heat from thermal operations promotes increased dissolution of residual NAPL and increased biological degradation rates. During EAB operations, the infrastructure for thermal operations is dismantled and removed from the Site.

The passive groundwater treatment system, as described in Section 3.2, Common Elements, and deemed necessary from performance monitoring, would be installed during the final stages of EAB. When EAB is terminated, hydraulic containment also would be terminated, and passive treatment operations begin. The passive treatment system would operate for approximately 20 years, after which all wells would be are abandoned, save a few monitoring wells, the GWTP is demolished, and the final Site cap is constructed, as described in Section 3.2, Common Elements.

In the Other Periphery target zone, EAB would be applied using an array of air and amendment injection points and wells. Supplemental biosparging points and wells for amendment injection and monitoring are installed as illustrated in Appendix B **Drawing 400-C-103** to provide injection points for air and nutrients to enhance aerobic biodegradation of contaminants.

3.3.5.4 Design Criteria and Basis for Approach

The following subsections present the design criteria and design basis for the key Alternative 5 treatment technologies.

ISS -Jet Grouting

The design criteria and basis for ISS-jet grouting of the North Deep (DNAPL) target zone is the same as described for Alternative 4 in Section 3.3.4.2.

Enhanced NAPL Recovery

Enhanced NAPL recovery rates were estimated using a decline curve analysis (American Petroleum Institute Publication 4711, 2011) along with Site-specific parameters for the recovery well spacing (approximately 55 feet), fraction of NAPL volume characterized as mobile (0.34), and the NAPL and soil physical properties. Based on the analysis (Appendix D), 3 years of operation would recover approximately ?~~60~~ percent of the mobile NAPL. The 55-foot spacing between recovery wells was optimized with the design basis for the steam injection well spacing.

Thermal Treatment

Thermal enhanced extraction utilizes the enhanced NAPL recovery wells and injects steam through a network of injection wells installed amongst the extraction wells in a repeated seven-spot configuration with a 30-foot spacing between steam injection and extraction wells. This pattern overlays with the 55-foot spacing between NAPL recovery (steam extraction) wells.

The primary design criteria for thermal enhanced extraction is the GWTP's 80-gpm available hydraulic capacity, which controls dewatering and vapor/fluid extraction rates, and hence the size of each treatment cell. Per this criteria, the Core, East Shallow (LNAPL), and North Shallow (LNAPL) target zones were divided into six treatment volumes (cells) ranging in size from 31,000 CY to 78,000 CY. The cells would be segregated by internal sheet pile walls as shown on Appendix B **Drawing 400-C-100**.

The design basis for Alternative 5 accounts for high naphthalene mass extraction rates. Naphthalene crystallization considerations start in the treatment train and within the extraction wells. Wellhead details are shown on Appendix B **Drawing 400-C-500** and include multipurpose drop tubes that allow measurements of water level, soil temperature at the bottom of the well, and access for steam cleaning of the well screen should naphthalene fouling degrade recovery rates. Steam can also be supplied through this location to clean the vapor instrumentation and piping at the wellhead.

The conveyance piping includes heat tracing to maintain high temperatures that minimize crystallization while providing access ports for periodic steam cleaning as a routine maintenance procedure. As shown on Appendix B **Drawing 400-C-600**, all extracted liquids and vapors are routed through a direct contact condenser specifically designed to remove NAPL sludge, solid-phase PAH, and any solids extracted from the subsurface. Steam condensation is expected to generate PAH solids that would be handled as shown on **Drawing 400-C-600**. This process flow diagram illustrates the primary treatment equipment required for the thermal component of Alternative 5 including vapor treatment in a thermal oxidizer.

The water from the thermal treatment is near ambient temperature, has a low NAPL content, and is routed to the GWTP for final treatment. The existing GWTP process flow diagram is shown on Appendix B **Drawing 400-C-601** with the proposed upgrades to increase its capacity to 140 gpm and handle higher temperature water shown on **Drawing 400-C-602**. The thermal treatment system layout is shown on **Drawing 400-M-101**.

Dewatering and Soil Vapor Extraction

Each of the three Core Area treatment cells includes six dewatering wells with the objective of lowering the water table as close to the Aquitard as practical. The total pumping rate is estimated to range from 60 to 80 gpm. The East Shallow (LNAPL) South, East Shallow (LNAPL) North, and North Shallow (LNAPL) treatment cells each have three dewatering wells. The objective for pumping in these cells is to lower the average water table elevation by 10 to 15 feet to expose the majority of the NAPL. The total pumping rate is estimated to range from 30 to 45 gpm. After lowering the water table, soil vapor extraction (SVE) is initiated using the NAPL extraction wells at a total rate up to 600 scfm.

Soil Heating and Mobile NAPL Recovery during Steam Injection

Once most of the mobile NAPL is recovered, thermal treatment would be used to recover additional NAPL through the steam enhanced recovery and distillation recovery steps (**Table 3-5b**). Steam injection is not expected to result in complete recovery of all NAPL due to subsurface heterogeneities. Under Alternative 5, the design assumption is for ?~~35~~ percent recovery achieved through a longer period of enhanced NAPL recovery preceding steam injection and more uniform heating during steam operations in each treatment cell. The estimated NAPL volumes characterized as residual, that require recovery or treatment through the distillation, dissolution, and EAB steps account for about ?~~65~~ percent of the original NAPL volume present in each treatment cell.

Of the 582,000 gallons of NAPL initially present in the “squared off” treatment cells, it is estimated that 208,000 gallons are recovered using enhanced pumping and steam enhanced recovery methods. The remaining 374,000 gallons of immobile NAPL are thermally recovered through volatilization into the extracted vapor phase, dissolution into extracted water, or EAB. Some COC mass is adsorbed by aquifer solids. Desorption of this mass is enhanced by steam injection, but this fraction is not considered further because the mass is very small relative to the total NAPL mass.

Residual NAPL Distillation during Steam Injection

The duration of steam distillation to achieve the NAPL mass reduction is calculated from the rate of steam injection and the total mass of steam required. A practical steam injection rate during NAPL distillation was determined from the surface treatment capacity for condensing extracted steam and for handling PAH solids. Based on practical mass and energy balances, the assumed steam injection rate during distillation is 6,500 pph. For this steam injection rate, initial production of solid PAHs in the treatment system for the Core treatment cells is on the order of 6,000 pounds per day. The total mass of steam required for the NAPL mass reduction would be more than the mass calculated from the ideal distillation model. Overall, the steam requirement averaged 1,000 lbs/CY and required a total injection of about 277 million pounds of steam. The thermal component in the six treatment cells requires about 5 years to complete based on the proposed approach.

EAB following Steam Injection

Soil temperatures remain elevated for a long period following the end of steam injection and afford the opportunity for continued volatilization and recovery of NAPL components. When steam injection is terminated, air injection is continued through the same system of wells. The vapor and groundwater extraction systems continue operating to maintain a depressed water table and recover the injected air. For design, the air injection rate is assumed to sweep the vapor pore volume within the treatment target once per day. A daily pore volume sweep corresponds to an air injection rate of 200 scfm. Air injection and extraction operates for 30 days following the end of steam injection while the water table is lowered in the next treatment target.

As subsurface temperatures decay further and after 30 days of operation, liquid and vapor extraction cease in the extraction wells allowing the water table to rise. Biosparging is then initiated into the warm saturated zone to enhance the aerobic degradation of remaining dissolved-phase and desorbing contaminants. Biosparging is implemented by pulsing air injection into rotating sets of wells at an average rate of 100 scfm and extracting from the vapor barrier at a similar rate. Biological degradation parameters (e.g., dissolved oxygen [DO] and oxidation-reduction potential [ORP] in groundwater and carbon dioxide in vapor barrier extraction) and groundwater PAH concentrations are monitored. This operation continues for six to nine months during steam injection in the next treatment volume.

The design basis for EAB is described further in the following subsection.

EAB of Other Periphery Target Zone

The Other Periphery target zone lies outside and partially within the footprint of the thermal enhanced extraction and the ISS treatment zones. The design basis for implementing EAB in this target zone and as a thermal treatment polishing step varies and depends on the following Site-specific factors:

- Oxygen requirement for aerobic biodegradation based on contaminant mass estimates (assume 1,000 standard cubic feet of air per kilogram of contaminant mass degraded)
- Air injection well radius of influence (assume 25 feet)
- Anticipated average air injection rate for soil properties, air distribution patterns, NAPL dissolution rates, and aerobic biodegradation rates of individual creosote components (assume 8 scfm per well).

NAPL dissolution, oxygen distribution and diffusion, and reaction rates combine to slow the process and reduce the efficiency of oxygen utilization, thereby requiring the injection of an excess of oxygen into the subsurface. The air injection rate in the EAB system would be estimated from the anticipated half-lives of contaminants in the groundwater at the Wyckoff Site and the partitioning of oxygen from air into groundwater during design. For naphthalene in groundwater, typical half-lives under ambient anaerobic conditions have been observed from 110 to 462 days with a recommended value of 258 days (HydroGeoLogic, 1999). For aerobic conditions, such as those created during EAB, the half-life of naphthalene in groundwater at ambient temperatures is typically about 30 days (Aronson et al., 1999).

3.3.5.5 Implementation and Sequencing

The implementation of thermal treatment under this alternative[5] would typically consist of the following steps:

1. Install all process piping, including heat tracing or equivalent, to maintain vapors at an elevated temperature up to the point of ex situ treatment.
2. Initiate dewatering from the six dewatering wells and pump water to the GWTP.
3. Reroute groundwater extraction piping from the enhanced NAPL recovery wells to the thermal pretreatment system, and increase the extraction rate to recover as much remaining mobile NAPL as practical.
4. Initiate SVE in the extraction wells and beneath the vapor barrier.
5. Initiate steam injection and use performance observations to optimize flow and withdrawal rates.
6. Cease steam injection after 270 days, and continue liquid and vapor extraction at decreased rates.
7. With elevated soil temperatures still present, initiate EAB through multipurpose wells.

[5] The steps described are based on conditions present in Core A and would likely vary for other treatment cells.

8. As subsurface temperatures decrease, cease liquid and SVE allowing the water table to rise. Continue SVE beneath vapor barrier at a rate matching the EAB injection rate. Continue EAB and monitor biological degradation parameters and COC concentrations for six months. Introduce amendments, as necessary, to optimize aerobic biodegradation of residual COCs by adjusting redox conditions and adding electron donors, acceptors, and nutrients as needed.
9. Remove and inspect extraction wellhead assemblies and downhole pumps, remove steam injection wellhead assemblies, disassemble piping (excluding air lines to injection wells) and manifolds, and refurbish all for reuse in subsequent treatment cells. Move to the next treatment cell in the sequence and proceed with constructing the piping system for injection and extraction.
10. The leapfrogging construction and operations sequence continues across the FPA proceeding from Core A to Core B, Core C, East Shallow (LNAPL) South, East Shallow (LNAPL) North, and last the North Shallow (LNAPL) target zone.

Implementing Alternative 5 would span approximately 9 years of sustained Site activity from initial design to the initiation of the passive groundwater discharge/treatment ~~(if necessary)~~. Assuming 2016 as the base year, the implementation sequence, assuming all elements of the alternative were fully funded, ~~which does not show the remedial design, bid evaluation and award steps,~~ would consist of the following activities:

Year 0	Year 1	Year 2	Year 3-4	Year 4 - 8	Year 9
• Construct common elements • GWTP O&M • Jet grout ISS North Deep (DNAPL)	• Construct common elements • GWTP O&M	• NAPL recovery O&M • GWTP O&M	• NAPL recovery • GWTP O&M • Thermal construction	• Thermal O&M • GWTP O&M • EAB	• Thermal well decommissioning • Construct passive groundwater discharge/treatent

Year 10	Year 11 - 27
• Passive groundwater discharge/ treatment O&M • Install final site cap	• Passive groundwater discharge/ treatment • GWTP demoiltion

3.3.5.6 Screening Evaluation

Screening of Alternative 5 – Thermal Enhanced Extraction and ISS against the criteria of effectiveness, implementability, and cost indicates that this alternative should be retained. This alternative would be effective because it would reduce toxicity, mobility, and volume through treatment, achieve protection in a reasonable timeframe, and reduce the need for long-term management. This alternative would use advanced treatment technology that requires an extensive network of injection and recovery wells that utilize the GTWP to recover NAPL and thermal oxidation to destroy vapor-phase contaminants. Thermal enhanced extraction has been deployed successfully at other sites. While the cost is high, due the volume of NAPL-contaminated material requiring treatment, this cost is not disproportionate to overall effectiveness.

3.3.5.7 Cost Estimate

The total present worth cost for Alternative 5, based on a 1.4 percent discount rate, is $1~~3~~42.1~~1~~ million with a -30/+50 percent cost range of $99~~3~~.4~~9~~ million to $213.1~~01~~ million. A breakout of total life cycle costs is provided in **Table 3-5a**.

3.3.6 Alternative 6—Excavation, Thermal Desorption, and Thermal Enhanced Extraction

Alternative 6 combines the excavation and MTTD technologies to treat NAPL source material present in the upper portion of the Core Area to a depth of 20 feet. Alternative 6, like Alternative 5, addresses the NCP requirement to develop an alternative that removes or destroys contaminants to the maximum extent feasible, eliminating or minimizing, to the degree possible, the need for long-term management.

This alternative includes the following components (**Table 3-6**):

- The applicable common elements listed in **Table 3-2**.
- Excavation and MTTD treatment of an estimated 81,300 CY of NAPL source material present within the top 20 feet of the Core Area. Before backfilling treated soil, a geosynthetic clay liner would be placed on the bottom of the excavation to create a vapor barrier to support subsequent thermal treatment operations.
- Thermal enhanced extraction in the Lower Core Area, between depths of 20 feet and the top of the Aquitard, and the East Shallow (LNAPL), North Shallow (LNAPL), and North Deep (DNAPL) target zones. Following completion of thermal treatment, EAB would be implemented as a polishing step to promote aerobic biodegradation of residual NAPL and dissolved/sorbed-phase COCs. Residual heat from the thermal treatment step would accelerate aerobic biodegradation promoting a higher degree of treatment.
- EAB in the Other Periphery target zone.

Under this alternative, excavation and thermal desorption would treat an estimated ?~~14~~ percent of the NAPL present in the FPA, while enhanced NAPL recovery and thermal enhanced extraction would remove an estimated ?~~21~~ percent and ?~~43~~ percent, respectively. Passive groundwater treatment (?~~1~~ percent) and natural attenuation (?~~3~~ percent) would address the remaining ?4 percent of the NAPL.

This alternative addresses RAOs #1 through #3 by excavating and/or thermally treating NAPL-contaminated soil to reduce COC concentrations to the defined PRGs. EAB would be implemented to complete any remaining treatment necessary to achieve Upper Aquifer soil and groundwater PRGs. RAO #4 is addressed through treatment of Upper Aquifer NAPL source material and MNA within the Lower Aquifer to reduce COC concentrations to the Lower Aquifer groundwater PRGs.

3.3.6.1 Excavation Methods – Description

To facilitate dewatering and soil excavations, the Core Area would be divided into nine (9) sheet pile cells (**Drawing 500-C-100**) with surface areas ranging from 10,000 to 16,000 ft^2. The sheet pile walls extend from the ground surface to the Aquitard. Sheet pile wall bracing would be accomplished using welded whalers and struts, which would be left in place for backfilling. Within each of the cells, two dewatering wells would be installed to lower the water table below a depth of 20 feet. Each dewatering well is estimated to yield 10 to 20 gpm. The dewatering wells would be left in place to assist with the thermal treatment portion of the remedy or used as monitoring wells.

3.3.6.2 Thermal Desorption Treatment – Description

MTTD would generally be performed as described for Alternative 3.

Additional infrastructure to support MTTD operations includes the following:

- **Sheet Pile Cells and Dewatering Wells** – would be installed to form the nine (9) cells in the Core Area and would be installed into the top of the Aquitard.
- **Soil Blending and Handling Building** – this is a metal building or fabric structure used for staging the soil in order to improve its uniformity prior to feeding into the MTTD. The building is constructed on an asphalt concrete pavement (ACP) pad with a concrete berm. The building atmosphere is ventilated through a vapor-phase GAC system to control odor and emissions. Trucks would dump over a ramp near the eastern building entrance. The feeder to the MTTD system would be placed in the building thus allowing for interior loading to reduce noise during night and weekend periods.
- **MTTD Pad** – an ACP lined pad for the MTTD equipment as well as the genset and fractionation tanks for quenching of treated soils. The pad is sloped for stormwater collection and to support treatment.
- **Soils Awaiting Analysis Pad** – ACP lined holding area divided into cells to stage soil while it is tested to support blending, re-treatment, and backfill determinations. The cells are constructed of ecology blocks stacked three high. A turn-around-time for PAH and PCP soil analysis of 3 days is planned.
- **Treated Soils Stockpile Area**- ACP lined pad holding up to 16,000 CY of soil awaiting confirmation that soil PRGs have been achieved prior to backfill placement.
- **Propane Storage Tank** – a 30,000 gallon storage tank placed on a concrete pad with cradles enclosed by ecology blocks. The tank also includes a vaporizer.
- **MTTD Genset** – a containment pad for the genset as well as fuel cell. The fuel cell would have a capacity of about 16,000 gallons and provide for an estimated 12 days of operation.
- **Existing GWTP** – the water from the dewatering wells would be treated through the GWTP.
- **Storm Water Infiltration Trench** – would handle stormwater from the Site as well as the Treated Soil Stockpile Area if it is contaminated and can't be direct discharged. Prior to construction of the trench, the soils in this area would be excavated to a depth of 7 ft and treated via MTTD.
- **Decontamination Pad** – including a fractionation tank, genset, and a powered wheel wash. The fractionation tank would also support dust control. This pad would be located along the main access road between the Treated Soils Stockpile and the Soil Blending and Handling Building. The road would be constructed with 12-inches of crushed rock over a geotextile fabric.
- **Existing Well** – the well would be used for process and dust control water supply.
- **Underground Piping and Cables**. The following would be run underground; dewatering well pipe to GWTP; propane service to the primary and secondary chambers; stormwater conveyance to the infiltration trench; power to MTTD control trailer and the Soils Blending and Handling Building. The dewatering well piping would be buried HDPE with stub ups at each of the cells. The discharge header from the dewatering wells would be connected to the transfer piping using fire hoses. The wells would be powered by genset.

3.3.6.3 Thermal Enhanced Extraction and EAB

The thermal enhanced extraction and EAB components of Alternative 6 are similar to that described for Alternative 5. The layout of these components is shown on **Drawing 500-C-101** (Enhanced NAPL Recovery Wells and Thermal Wells), **Drawing 500-C-102** (Vapor Cover), **Drawing 500-C-102 and 500-C-103** (Piping), and **Drawing 500-C-104** (EAB Wells).

3.3.6.4 Design Criteria and Design Basis

Propane consumption for the MTTD unit is estimated at 23 gallons per ton of soil treated or 3 million gallons total. Electrical power would also be required and would be obtained from a 750 kilowatt (kW) TIER IV genset (480-volt three-phase) with an estimated fuel consumption at 100 percent operations of 55 gallons/hour or 450,120 gallons of diesel total.

The treatment rate through the MTTD system is estimated at 20 tons per hour with an estimated maximum treatment rate of 480 tons/day. The system would operate 24 hours/day for 7 days/week, and with an 80 percent availability, the daily treatment rate is about 16 tons/hour or 380 tons/day for eleven (11) months.

The design criteria and design basis for the thermal enhanced extraction and EAB components are the same as described for Alternative 5.

3.3.6.5 Implementation and Sequencing Schedule

The general sequence of events for excavation and MTTD operations in each treatment cell would include the following steps:

1. During week days, excavation would be conducted in parallel with MTTD treatment.
2. During the week day night shift, and on weekends, soil would not be excavated but MTTD treatment would continue using stockpiled material loaded from the Soil Blending and Handling Building interior into the MTTD feeder to minimize noise levels. For extended weekends, excavation may be required or additional soil may need to be staged within the cells.
3. Excavation would begin in the first cell using a combination of long reach excavator and a drag line. Foam would be used to control odors during excavation. Soils with excess moisture may be staged in an adjoining contaminated cell for drying prior to transport to the Soils Blending and Handling Building.
4. As the excavation within a cell proceeds to the design depth, the whalers and struts would be installed using a crane and man lift to provide lateral support for the sheet pile walls.
5. As the excavation progresses a track mounted dozer would be lowered into the cell to support the staging of soils for removal by long reach excavator or clam shell.
6. Excavated soil would be transported in 20 ton off-road trucks to the Soil Blending and Handling Building where it would be staged for further dewatering (using a tiller) as well as blending and/or addition of admixtures. Soils would be end dumped over a dump ramp.
7. Soils in the Soil Blending and Handling Building would be windrowed for tilling or mixing to support dewatering and homogenization as well as adding reagents (such as lime) to support dewatering. The building would be designed to hold a 3 to 4 day supply of soil for MTTD treatment.
8. Soils within the Soil Blending and Handling Building would be loaded into the feeder of the MTTD unit, which is located within the building. This approach minimizes odors and dust, as well as reducing noise levels during nighttime and weekend operations.
9. Treated soil is staged by conveyor in day piles on the MTTD pad, where it is subsequently hauled to the Soils Awaiting Analysis pad where it is held in cells (one day's treatment per cell) until it has been demonstrated, through analytical testing, that the soil meets the treatment objectives.
10. Soil that doesn't meet the treatment objectives would be staged for re-treatment. Soil meeting the treatment objectives would be staged in the Treated Soils Stockpile area and/or staged for direct backfill adjacent to an excavation.

11. Prior to backfilling, sump pumps would be used for any further dewatering prior to the placement of the geosynthetic clay liner vapor barrier.
12. When two cells are open the backfilling operation would be conducted. Backfill would be placed in lifts and compacted. A crane would be used to lower equipment into each cell as required to support geosynthetic clay liner placement, spreading of backfill, and compaction. As indicated above the whalers would be left in place. As conditions dictate, the struts may be removed to support backfilling.

Once MTTD is completed the unit would be decontaminated and removed along with other surface and below ground (piling) features. ACP would be removed and recycled to the degree feasible. Subgrade gravel for base material would be removed from the Treated Soil Stockpile area and used along with other base materials for backfill within the cell or general Site.

The general duration of key excavation~~, and~~ MTTD, and thermal enhanced extraction treatment activities would include the following:

Year 0 • Construct common elements • GWTP O&M	**Year 1** • Construct common elements • GWTP O&M	**Year 2 - 3** • Soil excavation and MTTD • GWTP O&M	**Year 4** • NAPL recovery O&M • GWTP O&M
Year 5-6 • Construct thermal extraction system • Thermal extraction and NAPL recovery O&M • GWTP O&M	**Year 7 -9** • Thermal extraction O&M • GWTP O&M • Construct passive groundwater discharge/treatment system	**Year 10 -12** • Passive groundwater discharge/treatment O&M • Thermal decommissioning • Construct final site cap	**Year 13-27** • Passive groundwater discharge/treatment O&M

Following completed of excavation and MTTD treatment, thermal enhanced extraction and EAB would be implemented as described for Alternative 5.

3.3.6.6 Screening Evaluation

Screening of Alternative 6 – Excavation, MTTD and Thermal Enhanced Extraction against the criteria of effectiveness, implementability, and cost indicates that this alternative should be retained.

Alternative 6 is effective because it utilizes multiple treatment technologies, employing excavation and MTTD to address high concentration NAPL source material and thermal enhanced extraction to address areas where lower concentrations of NAPL source material occur. Although this alternative faces some implementation challenges, the design concept has developed approaches to address each condition. As described in the following subsection, the estimated cost for this alternative is higher relative to the other alternatives but provides important information that shows what is required to implement this technology combination at the Site.

3.3.6.7 Cost Estimate

The total present worth cost for Alternative 6, based on a 1.4 percent discount rate, is $197.7~~86~~ million with a -30/+50 percent cost range of $138.4~~0~~ million to $296.6~~79~~ million. A breakout of total life cycle costs is provided in **Table 3-6**.

3.3.7 Alternative 7—ISS of Expanded Core Area and Thermal Enhanced Recovery

This alternative employs an adaptive management or iterative approach that provides the opportunity to respond to new information and changing site conditions observed over the remedy implementation lifecycle. Under this alternative, remedial action target areas and technology selection would be refined based on the results of remedial design data collection, performance monitoring, and field observations made during a Phase 1 and Phase 2 implementation schedule. Remedial design data collection would be used to define the treatment area where Phase 1 remedial actions would be implemented while Phase 1 performance monitoring data would be used to determine the need for Phase 2 remedial action, and if so, which technologies should be used and where they would be implemented.

The primary components of this alternative (**Table 3-7a**) that would be implemented during Phase 1 include:

- The Common Elements listed in **Table 3-2**.
- ISS of an expanded Core Area (**Figure 3-2**).
- NAPL recovery at targeted locations in the North Deep and East Shallow areas where ISS is not performed with continued operation of the GWTP. Several existing groundwater extraction wells lying within the ISS footprint would be plugged and abandoned and replacement wells installed. For the purposes of this FFS, it's assumed that six wells would be replaced. The exact number of recovery wells necessary to maintain hydraulic containment will be determined during remedial design.
- Enhanced aerobic biodegradation (EAB) along the inside perimeter of the existing sheet pile wall using a network of vertical air sparge wells that inject atmospheric air in the upper portion (i.e.~~g.~~ Compartment 1) of the upper aquifer and trace nutrients (if necessary), to stimulate in situ biodegradation of dissolved phase COCs. The EAB system would create a treated groundwater shell along the downgradient margins of the FPA, that contains low or non-detect COC concentrations, to allow for passive groundwater discharge or cost efficient operation of a passive groundwater treatment system as a long-term upper aquifer water balance control measure.
- A 5 year performance monitoring period to assess Phase 1 treatment effectiveness. Data generated from the performance monitoring program would be compared to the defined Upper Aquifer and Lower Aquifer trigger criteria to determine the need for Phase 2 remedial action.
- Transition to passive groundwater discharge or passive groundwater treatment, at the end of the 5 year performance monitoring period, based on comparison of the performance results to the passive discharge and passive treatment trigger criteria as follows:
  - If the passive discharge (e.g. no treatment required) criteria are met, no further action would be performed.
  - If the passive treatment criteria are met, the performance monitoring data would be used to design the system and to prepare an O&M cost estimate. If the cost estimate indicates that O&M costs are substantially lower than operation of the GWTP, the passive treatment system would be constructed as described in Section 3.1 – Common Elements. If passive treatment costs are not substantially lower, then targeted Phase 2 remedial action would be implemented to treat additional NAPL source material such that the desired passive treatment cost threshold is achieved.

If Phase 1 performance monitoring reveals conditions that exceed the Phase 2 remedial action trigger criteria, then Phase 2 remedial actions would be implemented. These may include:

- Targeted treatment. A decision on which treatment technology or technologies to use, and the areas to be targeted, would be based on Phase 1 performance monitoring results. Candidate technologies include: ISS, thermal enhanced NAPL recovery, and in situ chemical oxidation. For the purposes of scoping and cost estimating in this FFS, thermal enhanced recovery across the Phase 2 treatment area shown on **Figure 3-2** is assumed.
- Continued operation of the GWTP to provide hydraulic containment and protection of the lower aquifer
- Performance monitoring to assess Phase 1 + Phase 2 treatment effectiveness.
- Transition from active to passive groundwater discharge or passive groundwater treatment as described for Phase 1.
- The estimated soil and NAPL volumes present in the Phase 1 and Phase 2 treatment zones are shown in **Table 3-7b**.

3.3.7.1 Adaptive Management and Trigger Criteria

A guiding principle for the adaptive management approach is to treat the most contaminated area first and expand treatment to other areas, as determined by performance monitoring data, to efficiently achieve the performance objectives[6] (PO) and RAOs. Initial ISS activities and NAPL recovery are expected to achieve PO#1 and the RAOs leaving PO#2 and confirmation that RAO #3 has been achieved as the focus for adaptive management decisions. PO#2 is interpreted as transitioning Site remedial activities to maintenance of the site cap and operation of the passive groundwater discharge/ treatment system to maintain achievement of the RAOs.

Key site conditions and elements of the Phase 1 remedial action that warrant an adaptive management approach for NAPL treatment within the FPA include the following:

- Installation of a new sheet pile wall inside the existing perimeter sheet pile wall, and a reinforced concrete bulkhead constructed between the two sheet pile walls, will physically contain contaminated soil while providing a significant physical barrier to future NAPL and dissolved phase contaminant transport from the upland to the beach. This is expected to result in lower PAH concentrations in the groundwater that upwells within the intertidal area.
- Phase 1 actions will result in a significant reduction in the contaminant mass flux that is generated from upper aquifer groundwater contact with pooled and residual NAPL. ISS of the expanded Core Area will also alter upper aquifer groundwater flow patterns, and potentially lower aquifer groundwater recharge of the upper aquifer. A clear understanding of these changes is needed to inform the need for and scope of Phase 2 remedial actions.
- Remedial action planned for the East Beach and North Shoal areas within OU1 will reduce NAPL concentrations in the top 30 inches of sediment, where recreational and ecological exposure can

[6] PO #1. Remove or treat mobile NAPL in the Upper Aquifer to the maximum extent practicable such that migration and leaching of contaminants is significantly reduced.

PO #2. Implement a remedial action that does not require active hydraulic control as a long-term component of O&M following completion of source removal action.

potentially occur, by removing contaminated sediment and placing sorbent caps over NAPL transport pathways.

The components of the OU2/OU4 and OU1 remedial actions described above will result in significant risk reductions at the Site, and collectively, may achieve the POs and RAOs without the need for treatment of the entire 10% RE NAPL footprint.

To guide decisions on the need for Phase 2 remedial action, a set of upper aquifer (**Figure 3-3a**) and lower aquifer (**Figure 3-3b**) trigger criteria were developed as components of Alternative 7.

A key element of the trigger criteria is a Phase 1 performance monitoring program that includes baseline (pre-treatment) and post-treatment Upper Aquifer and Lower Aquifer NAPL and groundwater monitoring with the monitoring results compiled and compared to the trigger criteria to determine the need for Phase 2 remedial action.

An additional element of the Alternative 7 trigger criteria is a decision point for transitioning from active groundwater treatment to passive groundwater discharge/treatment. Passive groundwater discharge consists of maintaining the Upper Aquifer groundwater elevation, at a level to be determined during remedial design, by draining the overflow to Puget Sound without treatment.

Passive treatment is similar except the overflow would be treated as described in Section 3.1 – Common Elements prior to discharge. Because passive treatment will incur routine O&M costs; associated with periodic inspections, sampling to confirm treatment effectiveness, and replacement of spent media, for an extended period of time it's important the cost not exceed a reasonable level. Passive treatment O&M costs are largely controlled by the volume of treatment media required and the frequency of spent media changeout with both of these factors defined by the passive groundwater flow rate and the COC concentrations present in Upper Aquifer groundwater at the time treatment occurs. To ensure that O&M costs are reasonable, should passive treatment be required, an additional trigger has been included that would require Phase 2 remedial action.

Commented [YCK(14]: Another O&M cost is the regulatory compliance cost, increasing cost with increasing discharge points.

3.3.7.2 Phase 1 Predesign Investigation

To support remedial design of the ISS, NAPL recovery, and EAB remedy components, a predesign investigation would be conducted. The predesign investigation would include the following activities:

a. TarGOST Investigation – to refine the footprint where Phase 1 ISS would be deployed, a series of TarGOST borings would be drilled around the perimeter of the Expanded Core Area.
b. Groundwater Sampling – to establish baseline groundwater quality conditions, two rounds of groundwater monitoring would be conducted. The first event would be performed under high groundwater elevation conditions similar to passive discharge elevations, and the second prior to Phase 1 implementation. It's assumed that 20 existing wells will be sampled. Lower Aquifer groundwater sampling is being performed as part of the current remedy. These data will be compiled for use as part of the predesign investigation data evaluation.
c. GWTP Data Compilation – existing GWTP influent SVOC results for a 2 year period will be compiled for use in defining a mass flux baseline to support implementation of the Phase 2 trigger criteria. This information will be obtained from process control monitoring performed under the current remedy.
d. Air Sparge Pilot Test – to develop performance information (flow rate and radius of influence) to support design of the Phase 1 EAB system, a pilot test will be conducted. This will consist of installing two typical air sparge wells screened in the upper aquifer, injecting compressed air spiked with a tracer for up to 24 hours to span a full tidal cycle, and measuring water levels and collecting groundwater samples from adjacent monitor wells for tracer analysis.

e. Surface Geophysical Investigation – to confirm the extent of buried debris within the expanded Core Area, a surface geophysics survey will be conducted. This survey will also include excavation of 3 to 5 deep test pits to confirm the geophysical survey results and to assess the presence of buried debris.
f. ISS Mix Design – laboratory bench-scale testing will be performed using creosote contaminated material obtained from the TarGOST and/or geophysical survey test pit work to refine the design for the ISS stabilization agent. The testing includes blending a series of creosote contaminated samples with varying reagent concentrations and evaluating performance using unconfined compressive strength, hydraulic conductivity, and leachability analysis.

3.3.7.3 Phase 1 ISS Treatment

The primary component in Alternative 7 is ISS treatment in the Expanded Core Area to treat NAPL contaminated material down to the depth of the contamination, which varies across the treatment footprint area. If the remedial design investigation determines that ISS treatment in additional areas may be warranted or treatment of previously identified areas may no longer contribute towards achievement of the POs and RAOs, the ISS treatment area can be readily modified per the adaptive management approach.

Deployment of the ISS technology in the expanded Core Area would be similar as described under Alternative 4, treating approximately ? percent of the NAPL source material present in the FPA. Four existing hydraulic containment wells, lying within the ISS treatment footprint, would be plugged and abandoned beforehand.

The ISS footprint for Alternative 7 is shown in Appendix B Drawing 700-C-100 with details for the assumed depth of treatment illustrated in Drawings 700-C-101 through 700-C-105. As shown in Drawing 700-C-105, the ISS action provides a substantial cut off wall between the southern and northern areas of the site but leaves a gap between the bottom of the ISS and the Aquitard in the eastern portion of the ISS treatment. Hence, hydraulic communication between the two zones will be substantially lessened but not eliminated. The impact of these changes in site hydraulics on the passive discharge system can only be assessed with confidence after implementation.

3.3.7.4 Phase 1 NAPL Recovery and Hydraulic Containment

Concurrent or even preceding ISS deployment, NAPL recovery would be implemented using an array of new and/or existing recovery wells installed at targeted locations in the North Deep and East Shallow areas (**Figure 3-2**). Where NAPL is pooled along the water table (LNAPL) or on low permeability layers (DNAPL) within the upper aquifer, inducing NAPL to flow to recovery wells is an effective means of achieving significant contaminant mass reduction, which in turn may increase the effectiveness of other treatment technologies (e.g. EAB). NAPL recovery would be performed by increasing the horizontal hydraulic gradient across the area where mobile NAPL occurs via direct NAPL pumping in the East Shallow area and total fluids extraction coupled with NAPL separation and water re-injection in the North area.

The NAPL recovery system for the North area is designed to remove both LNAPL and DNAPL in the area by screening the recovery wells across the entire saturated zone. Groundwater is extracted to reduce the hydraulic head at the recovery well. Extracted groundwater is treated in an oil water separator to separate oil from groundwater and then the water is reinjected upgradient of the recovery wells through screens at the top of the Aquitard targeting DNAPL for recovery. This “water flooding” system steepens the hydraulic gradient in the vicinity of the recovery well increasing NAPL recovery effectiveness.

The NAPL recovery system in the East Shallow area is designed to remove LNAPL. The system includes skimming pumps with sensors that detect when the pump is in LNAPL thereby it pumps only pumps LNAPL and not LNAPL and groundwater. The pump and transfer piping are suspended on a reel that automatically lowers and raises the pump within the well to keep the pump intake in the NAPL. This is important with the fluctuating water levels attributed to tidal and seasonal water level conditions. Recovered LNAPL will be collected in a satellite tank for periodic transfer to the GWTP NAPL storage tank.

The estimated layout of the Phase I NAPL recovery wells is illustrated in Appendix B Drawing 700-C-106 and Drawing 700-C-107. The exact number and optimum placement of the recovery wells may change during remedial design based on evaluation of updated information. NAPL recovery infrastructure in the North Deep area includes a line of seven extraction wells aligned with the sheet pile wall accompanied by surface separation equipment and an upgradient line of seven water re-injection wells. In the East Shallow area there are 23 recovery wells fitted with skimming pumps and a single injection well for discharge of any co-extracted groundwater.

Concurrent with NAPL recovery, the balance of the wellfield will be operated to maintain hydraulic containment. This will consist of operating the system at a total flow rate of 35 to 40 gpm, and adjusting individual well flows as needed. Because several existing hydraulic containment wells will have to plugged and abandoned to allow for ISS, groundwater pumping from the new recovery wells will be used to supplement hydraulic containment pumping. Drawing 700-C-106 shows the location of existing PW wells employed for hydraulic containment and the proposed locations for six new groundwater extraction wells to replace those abandoned for ISS. Water level measurement data from the in well transducers will be downloaded every three months and the data evaluated in accordance with the current protocol to assess hydraulic containment effectiveness.

Recovered groundwater would be treated at the existing GWTP as described for Alternative 2. NAPL recovery volumes measured at the GWTP and NAPL thickness measurements in recovery wells and adjacent monitoring wells would be compiled and the data used to optimize recovery operations. Periodic NAPL transmissivity tests would be performed to measure the ability of the formation to provide NAPL to the recovery wells. Optimization may include increased or decreased groundwater pumping rates, shifting NAPL recovery equipment to other existing well locations or converting recovery/monitoring wells into treated water injection wells to enhance gradient induced recovery.

3.3.7.5 Phase 1 - Enhanced Aerobic Biodegradation

The EAB element consists of a linear array of vertical biosparge wells installed parallel to and offset 15 to 30 feet inland from the sheet pile wall. The biosparge wells inject atmospheric air, containing 21 percent oxygen and trace nutrients (if necessary), into the upper aquifer to accelerate in situ biodegradation of residual NAPL and dissolved phase COCs. For this FFS, the biosparge wells are installed on 50 ft centers (30 ft radius of influence for each well) along an approximate 1500 ft section of the sheet pile wall (27 biosparge wells total) as illustrated in Appendix B Drawing 700-C-106. Each well would receive an air flow rate of 11 scfm (300 scfm total) from a compressor installed in the GWTP building. The EAB system would be installed during the initial Phase 1 construction efforts so that operations can be optimized to achieve the highest levels of treatment.

The EAB system would create a shell of aerobic groundwater just inside the sheet pile wall, with dissolved phase COCs present at non-detect to low concentrations, from which the passive discharge/treatment system would draw water. If the EAB system is highly effective, then the passive system could discharge groundwater directly to the intertidal area below the mudline without treatment. If the system is marginally effective, then passive treatment would occur before discharge.

Because air injection creates a groundwater elevation mound around the injection point, biosparging would be performed while the tide is rising with the system turned off during the outgoing tide to promote upper aquifer groundwater flow into the passive system. The GWTP - PLC would be programmed to turn the compressor on and off based on the tide schedule or using a water level sensor installed below the low point of the water table.

Sampling and analysis (see Section 3.3.7.5) of the passive system influent and selected monitoring wells located along the sheet pile wall perimeter would be used to assess EAB effectiveness and to optimize biosparge operations.

3.3.7.5 Phase 1 Performance Monitoring

To assess the effectiveness of Phase 1 ISS, NAPL recovery, and EAB for comparison to the Phase 2 trigger criteria and to assess achievement of POs and RAOs, an upper and lower aquifer performance monitoring program will be implemented. This program would include the following:

1. **In well NAPL Thickness.** Measurements would be performed at a subset of upper aquifer and lower aquifer monitoring wells. For the purposes of this FFS, it's assumed that NAPL measurements will be performed monthly at 20 upper aquifer wells and 10 lower aquifer wells during the first year, quarterly in years 2 and 3, and semiannually in years 4 and 5.
2. **NAPL Transmissivity Tests.** NAPL recovery is effective for as long as the formation can effectively transmit NAPL to the wells. At some point, pooled NAPL gets separated into smaller pockets and the NAPL transmissivity decreases. Therefore, periodic measurements of NAPL transmissivity will be performed. Standard ASTM procedures will be used.
3. **Water Level Measurements.** Upper aquifer groundwater elevations are influenced by hydraulic containment pumping, tidal fluctuations, and seasonal rainfall variations. The effect of these events will continue during Phase 1 remedial action with additional effects arising from installation of the new sheet pile wall and perimeter bulkhead and ISS of a large block of upper aquifer material within the central portion of the FPA. To assess the effects of these events on upper aquifer groundwater flow patterns and contaminant transport, water level measurements will be performed at a majority of the existing upper aquifer and lower aquifer monitoring well locations. For the purposes of this FFS, it's assumed the measurements will be performed monthly for year 1 and semiannually for years 2 through 5. This data set will be supplemented with continuous water level monitoring data obtained from transducers installed in the hydraulic containment network. Tidal stage information from the Eagle Harbor gaging station will also be downloaded from the NOAA website to supplement the upland water level data.
4. **Groundwater Sampling and Analysis.** As shown on **Figure 3-3a and Figure 3-3b**, COC concentrations present in upper and lower aquifer groundwater are a key data input to the Phase 2 remedial action trigger criteria evaluation. ISS treatment will result in a new COC concentration distribution and new groundwater flow patterns within the area bounded by the expanded Core Area footprint and the perimeter sheet pile wall and it may take several years before an equilibrium is achieved. To assess the effectiveness of ISS treatment, groundwater samples will be collected from a subset of upper aquifer and lower aquifer monitoring wells. For the purposes of this FFS, it's assumed that samples will be collected from 10 upper aquifer wells quarterly for year 1, and semiannually for years 2 through 5. In the lower aquifer, groundwater samples will be collected from 10 wells semiannually for years 1 through 5.

5. **Dilution - Attenuation Factor (DAF) Determination.** COCs present in upper aquifer groundwater that lies below the passive discharge/treatment system invert elevation would eventually discharge to the intertidal area after the hydraulic containment/GWTP system is eventually turned off. The length of this flow path and the magnitude of the COC concentration reduction that occurs through dilution and attenuation is expected to vary both spatially and temporally. The presence of the sheet pile wall, and the tidally induced gradient reversals that occur across the aquitard, likely result in a very tortuous flow path. As shown on **Figure 3-3a**, the magnitude of this DAF is currently estimated to be 20 and will be refined during remedial design using a groundwater flow and transport model.

   A DAF will also be defined for the passive discharge/treatment system. The outfalls for this system would terminate below the mudline thus allowing the effluent to mix with groundwater and sediment pore water upwelling through the sediment column. The methodology to be used for defining the DAF will be developed as part of the passive discharge/treatment system remedial design.

6. **Data Evaluation and Reporting.** Phase 1 performance monitoring data will be compiled periodically and an annual report issued. Reports for years 1, 2 and 3 will focus on remediation accomplishments while those prepared for years 4 and 5 will focus on evaluating the data relative to the Phase 2 triggers. The data compiled for these reports will also be used to support the 5 year reviews.

3.3.7.6 Phase 1 Passive Groundwater Discharge or Passive Groundwater Treatment

Because of natural recharge sources (e.g. rainfall, upgradient inflow, and Lower Aquifer groundwater upflow), it is expected that upper aquifer water level control will be needed for long-term site management. To maintain the upper aquifer groundwater level at a not-to-exceed elevation to be determined during remedial design, a passive drainage system will be installed as described in Section 3.1 – Common Elements at locations illustrated in Appendix B Drawing 700-C-108. Phase 1 performance monitoring data will provide the input required for the design of this system, such as the groundwater elevation and dissolved phase COC concentrations.. It is expected that after 3 to 4 years of Phase 1 treatment performance monitoring data have been compiled, and the effectiveness of the EAB system is well defined, a determination will be made on whether a passive discharge system or a passive treatment system is required. If a passive treatment system is needed, a preliminary design and O&M cost estimate will be prepared to determine if the system meets the O&M cost trigger (**Figure 3-3a**). If the O&M cost trigger is met, and other performance monitoring data indicate that Phase 2 remedial action is not required, the system would be constructed near the end of the 5 year Phase 1 performance monitoring period.

Commented [YCK(15]: I think that we agreed to continuing operating the groundwater treatment plant post Phase 1. If that is the case, I am not sure that we will be able to assess the effectiveness of the EAB system given the upgradient dissolved phase concentration is effected by the treatment plant. We may need to turn off the treatment plant at some point post Phase 1 to better assess the EAB system.

3.3.7.7 Phase 2 – Thermal Enhanced NAPL Recovery

If Phase 1 performance monitoring data indicate that Phase 2 remedial action is required, the data would be evaluated to determine which technology is best suited to address the conditions that prevent achievement of PO #2 and the RAOs. Candidate technologies include ISS, ISCO, and thermal enhanced NAPL recovery. Localized areas with high levels of NAPL contamination would favor the use of ISS and ISCO whereas as larger areas with more disperse contamination might favor thermal enhanced recovery. For the purposes of this FFS, it's assumed that thermal enhanced recovery would be implemented within the Phase 2 area shown on **Figure 3-2**. Thermal enhanced NAPL recovery would be implemented using "wet" steam injection.

Wet steam injection employs a mix of liquid and vapor at steam temperature to provide substantial energy injection rates without creating a continuous steam vapor zone. The approach promotes NAPL mobilization for recovery by reducing NAPL viscosity, increasing the solubility of NAPL components thereby increasing residual NAPL dissolution rates while providing a hydraulic gradient exceeding that of liquid water injection alone. In addition, there is no continuous steam zone or multi-phase (vapor and liquid) wastestream thereby simplifying above ground treatment. However, because the groundwater temperature and throughput rates would increase, the GWTP would be upgraded to accommodate throughput rates up to 140 gpm with provisions for an influent temperature estimated at 95 to 105 ºF. Introduction of thermal enhancements would proceed across the Phase 2 footprint to mobilize and recover NAPL, increase dissolution rates from immobile NAPL, and increase in situ biological degradation rates. It is estimated that Phase 2 target soil volumes could be moderately heated to an optimal average temperature of about 140 ºF in about one year.

Commented [YCK(16]: Is that true assuming wet steam injected is less than the liquid mass injected for liquid water injection alone?

After initial heating of the treatment area, NAPL recovery, dissolved-phase extraction, and hydraulic containment would continue as needed along with operation of the GWTP. The hot groundwater extracted from the subsurface would pass through heat exchangers to transfer the extracted energy to treated water piped for re-injection. This would significantly decrease the energy required to maintain an elevated subsurface temperature. Periodic addition of heat through wet steam injection would be performed in areas where temperatures are low or subject to encroachment of ambient groundwater from outside the target soil volumes. Operation of the thermal enhanced NAPL recovery is anticipated to occur for up to 4 years beyond the initial one year heating period. Per the adaptive management approach, annual evaluations of contaminant mass recovery rates would be performed and appropriate optimization steps implemented, such as intensifying treatment or terminating treatment in areas where NAPL recovery rates have diminished and dissolved phase COC concentrations have stabilized. Portions of the site could also transition to other technologies such as ISCO or EAB as conditions dictate.

Table 3-7c lists the estimate for the initial NAPL volume in each target soil volume including the ISS volume for reference. The Phase II estimates include the Phase I targets as these are included in the Phase II operations. The third column provides the estimated duration of wet steam injection required for the initial heating of the volume from ambient temperature to the target average temperature of 140 ºF. If the soil volumes are heated sequentially, the total time required is 216 days of continuous injection. The estimates for NAPL recovery from direct pumping enhanced by thermal within each target treatment volume (or sequestered by ISS) are listed in the fourth column. Under ambient conditions, the percentage of NAPL deemed mobile based on TarGOST results is 34%. From literature reviews, heating and the consequent reduction in creosote viscosity and reduction in residual saturation provides a 50% increase in the percentage of NAPL that is mobile (i.e., 1.5 x 34% = 51%). It is reasonable to assume 75% recovery of the mobile NAPL over the full term of the Phase II effort (5 years). Based on these assumptions, approximately 70,000 gallons of NAPL is recovered during Phase II, and when combined with ISS represents an overall reduction in NAPL of 77%. The residual NAPL left for treatment by dissolution and degradation at elevated temperature is about 113,000 gallons. Based on the soil volume in each target (or pore volume) and estimated residual NAPL, the flushing rate to achieve an exchange of ten pore volumes in four years is provided in the final column. The total flushing rate is coincident with the anticipated capacity of the GWTP available for the thermal operations. A flush of ten pore volumes at elevated temperature is consistent with efforts at other creosote sites and dissolution modeling accompanied by biological degradation also indicates ten pore volumes is sufficient to achieve a reduction in equilibrium groundwater naphthalene concentration of over 90%. Such a reduction is expected to make passive discharge or passive treatment viable at the end of the thermal operations.

The wells installed for Phase I NAPL recovery would be included in the well field for Phase II thermal enhanced recovery as illustrated in Appendix B Drawing 700-C-109 and in more detail on Drawings 700-C-110 and 700-C-111. As shown, Phase II necessitates the additional installation of 67 extraction wells and 39 injection wells, both assumed to have 4-inch diameters, as well as 97 temperature monitoring wells located among the injection and extraction wells. Pneumatically driven pumps are assumed suitable for the total liquids pumping from the wells.

Following well installation, other infrastructure includes piping, fittings, instrumentation, and surface process systems. Wellhead designs for extraction, injection and biosparging are provided in Drawing 700-C-112. New surface process components are limited to liquid treatment that includes:

1. Place process equipment for pre-treatment of extracted liquids ahead of the existing Groundwater Treatment Plant (GWTP) (e.g., accumulation tank, heat exchangers, NAPL separators, NAPL storage tank, and connecting pipes).
2. Place a propane storage tank (30,000 gallons).
3. Place a propane-fired steam generation system capable of producing 10 million BTU/hr and connect to propane tank.

The process flow diagram of surface equipment preceding the existing GWTP is shown in Drawing 700-C113. The process includes a 20,000 gallon accumulation tank into which all extracted liquids are pumped. This tank acts as the first oil separator because of its slow velocity. Skimmed LNAPL and DNAPL are pumped directly to the existing oily waste storage tank. From the accumulation tank, the liquid is directed through a 150 gpm oil water separator for additional NAPL recovery. From the oil water separator the hot water is routed through heat exchangers to transfer energy to treated water for re-injection and then through a second set of heat exchangers to reduce the temperature to an acceptable level for entry to the existing GWTP for treatment prior to discharge or re-injection. The equipment site plan for the Phase II surface system is illustrated in Drawing 700-C-114.

Enhanced Biological Degradation

Following completion of thermal enhanced NAPL recovery, EAB would be performed using existing Phase 2 injection and recovery wells to compliment the continuing EAB along the entire site perimeter. Because subsurface temperatures will be elevated, EAB will be an effective polishing step that would provide added assurance that PO #2 and RAOs will be fully achieved. Installation of the surface components for the EAB system consist of placing two air compressors, installing pipe and instrumentation between the compressors and air sparge wells, and a control system to regulate air injection. The duration of Phase 2 EAB operations is assumed to be 2 years for the purposes of this FFS but it may be extended or shortened depending on thermal enhanced recovery and EAB performance monitoring results.

The calculated NAPL volumes characterized as residual and requiring dissolution and degradation or extraction are summarized in Table 3-7c for each target volume. Aerobic biodegradation can be more effective in larger volumes since more volume is available for microbes to inhabit. The primary variables governing degradation, beyond oxygen availability, are temperature and dissolution rates from residual NAPL. In general, the higher the NAPL saturation, the higher the dissolution rate because of larger contact area between water and NAPL. Equilibrium between the groundwater and NAPL cannot be assumed if degradation is relatively rapid.

A common assumption for the bulk mass transfer at hydrocarbon NAPL sites under ambient conditions is 0.05 day^{-1} (Mobile et al., 2012). With the agitation provided by hydraulic containment pumping and air injection, this value is assumed double for the purposes of this FFS. Under ambient conditions and temperatures, if sufficient oxygen is provided, the half-life of dissolved naphthalene in groundwater is typically about 30 days (Aronson et al., 1999). This value is assumed for the Wyckoff Site at a system temperature of 12 °C. Heating the subsurface to 40 °C is expected to reduce the half-life by a factor of 4 in the presence of abundant oxygen. For periphery area, outside the air sparge zone, an aerobic naphthalene half-life of 7.5 days is assumed.

3.3.7.7 Phase 2 - Passive Groundwater Discharge or Passive Groundwater Treatment

At the conclusion of Phase 2 thermal enhanced recovery, a passive groundwater discharge or passive groundwater treatment system would be designed and constructed as described for Phase 1.

3.3.7.8 Implementation Sequence and Schedule

Commented [YCK(17]: Do we need to include a reference here for the Phasing and Sequencing memo?

Implementing Alternative 7 would span approximately 13 years of sustained Site activity from initial design to the initiation of the Phase 2 passive groundwater treatment as described below.

The sequence and duration of key Alternative 7 Phase 1 and Phase 2 activities, assuming all elements of the alternative are fully funded, includes the following:

Year 0: Phase 1	Year 1: Phase 1	Year 2: Phase 1	Year 3: Phase 1	Year 4 – 5: Phase 1	Year 6 – 10: Phase 1
• Project planning • GWTP O&M (State lead)	• Construct common elements • Construct NAPL recovery and EAB wells • NAPL recovery, EAB, and GWTP O&M • GWTP O&M	• Construct common elements • NAPL recovery, EAB, and GWTP O&M	• Construct common elements • NAPL recovery, EAB, and GWTP O&M	• ISS of Expanded Core Area • NAPL recovery, EAB, and GWTP O&M	• Design, construct, operate, passive groundwater discharge/treatment (if applicable) • Phase 1 performance monitoring • Phase 2 determination (year 10)

Year 11: Phase 2 (if necessary)	Year 12 – 15: Phase 2	Year 16: Phase 2	Year 17-34: Phase 2
• Construct thermal enhanced recovery • Construct common elements (outfall) • EAB O&M	• Thermal enhanced recovery O&M • EAB O&M	• Thermal decommissioning • Passive groundwater discharge/treatment construction Construct common element (final cap)	• Passive groundwater discharge/treatment O&M

3.3.7.5 Cost Estimate

The total present worth cost for Alternative 7, based on a 1.4 percent discount rate, is $110.1 million with a -30/+50 percent cost range of $77.0 million to $165.1 million. A breakout of total life cycle costs is provided in **Table 3-7a**.

SECTION 4

4 Detailed Analysis of Alternatives

This ~~chapter~~Section presents the detailed analysis of remedial action alternatives described in Section 3.3 for the Wyckoff Soil and Groundwater OUs. The remedial action alternatives were evaluated against seven of the nine CERCLA criteria described in the NCP (“Remedial Investigation/Feasibility Study and Selection of Remedy,” 40 CFR 300.430€[9]). The CERCLA evaluation criteria are described in **Table 4-1**, and each of the remedial action alternatives evaluated individually and comparatively against these criteria in Sections 4.2 and 4.3, respectively. The remaining two criteria, which are identified as modifying criteria, are formally assessed during preparation of the Proposed Plan (State Acceptance) and following review of public and stakeholder comments (Community Acceptance) on the Proposed Plan.

The detailed and comparative analysis of alternatives helps to develop the information necessary to recommend an alternative in this FFS and assist in identifying a preferred alternative in the Proposed Plan. Following public and stakeholder review of the Proposed Plan, EPA and Ecology would select a final remedial action alternative for the Soil and Groundwater OUs and identify the selected alternative in a CERCLA decision document.

4.1 Description of CERCLA Evaluation Criteria

The nine CERCLA evaluation criteria upon which the detailed and comparative evaluations are based are designed to enable the analysis of each alternative to address the statutory, technical, and policy considerations necessary for selecting a final remedial alternative. These evaluation criteria (**Table 4-1**) provide the framework for conducting the detailed analysis of alternatives and selecting an appropriate remedial action. The performance or acceptability of each alternative is first evaluated individually, so relative strengths and weaknesses may be identified (Section 4.2), and then comparatively (Section 4.3) to assess trade-offs and to aid in an alternative ranking.

The evaluation criteria are divided into three categories (threshold, balancing, and modifying) based on the function of each category in the remedy selection process. The NCP (“Remedial Investigation/Feasibility Study and Selection of Remedy,” 40 CFR 300.430[f]) states that the first two criteria—protection of human health and the environment (HHE) and compliance with ARARs—are “threshold criteria” that must be met by the selected remedial action unless a waiver can be granted under CERCLA (“Cleanup Standards,” Section 121[d][4]).

The five “balancing criteria” represent technical considerations, upon which the detailed analysis is primarily based and include long-term effectiveness and permanence; reduction of toxicity, mobility, or volume (TMV) through treatment; short-term effectiveness; implementability; and cost. The cost estimate details and supporting information are included in Appendix C. In assessing how well each alternative performs relative to the balancing criteria, the fraction of NAPL mass that is treated by each alternative is a key subfactor.

The final two criteria—State and Community Acceptance—are “modifying criteria.” State Acceptance is formally assessed during preparation of the Proposed Plan, and Community Acceptance is formally assessed following review of Tribal Nations, public, and stakeholder comments on the Proposed Plan. Community and State Acceptance are not addressed in this FFS. Based on information from public participation, EPA and Ecology may modify some aspects of the preferred alternative or decide that another alternative is more appropriate.

4.2 Individual Analysis of Alternatives

This section evaluates each of the remedial action alternatives retained from the screening presented in Section 3.3 against the CERCLA threshold and balancing criteria described in **Table 4-1**. The evaluation results are presented in a narrative and tabular form. The tabular format also provides a pass (yes)/fail (no) determination for each threshold criteria and a rating for each of the balancing criteria. The rating is designed to assist with the comparative evaluation of alternates presented in Section 4.3 and identification of a recommended alternative in ~~Chapter~~Section 5. The three rating factors used include the following:

★★★ = A~~The a~~lternative expected to perform~~s~~ very well against the CERCLA balancing criterion with minimal disadvantages or uncertainties

★★☆ = ~~The a~~Alternative expected to perform~~s~~ moderately well against the CERCLA balancing criterion but with some disadvantages or uncertainties

★☆☆ = ~~The a~~Alternative expected to perform~~s~~ less well against the CERCLA balancing criterion with more disadvantages or uncertainty

4.2.1 Alternative 1—No Action

This alternative was developed per NCP requirements ("Remedial Investigation/Feasibility Study and Selection of Remedy," 40 CFR 300.430[e][6]) to provide a baseline for comparison to other alternatives. Alternative 1 – No Action represents a scenario where no access restrictions, ICs, or active remedial actions would be taken. Under this alternative, hydraulic containment pumping would cease in year 2015, and no further maintenance of access restrictions (fencing) or ICs would be performed. Absent hydraulic containment pumping, NAPL and dissolved-phase contaminants would migrate towards Eagle Harbor and Puget Sound resulting in potential for greater human and ecological receptor exposure to contaminants within the intertidal area.

Evaluation of Alternative 1 against the CERCLA threshold criteria (**Table 4-2**) indicates this alternative would not protect HHE nor would it comply with chemical-specific ARARS for protection of marine surface water quality. Because this alternative would not protect HHE nor comply with chemical-specific ARARS, it cannot be selected under CERCLA. Therefore, an evaluation against the CERCLA balancing criteria was not performed.

4.2.2 Alternative 2—Containment

Alternative 2 is the contingent remedy implemented under the 2000 ROD. This alternative is included in this FFS to satisfy the NCP requirement to develop a source control alternative that involves little or no treatment and protects HHE by preventing or controlling exposure to contaminants through engineering controls, and as necessary, ICs.

Evaluation of Alternative 2 against the CERCLA threshold criteria (**Table 4-3**) indicates this alternative would protect current and future human health by restricting land use and Upper Aquifer and Lower Aquifer groundwater use. Protection of HHE also would be achieved by operating the hydraulic containment system to reduce or prevent NAPL and dissolved-phase contaminant migration to Eagle Harbor and Puget Sound. Installing the soil cap and replacement sheet pile wall (common elements) would provide additional protection for ~~of~~ HHE by placing barriers that protect against direct contact exposure and reduce contaminant flux to Eagle Harbor and Puget Sound. This alternative would comply with action and location-specific ARARs and is expected to comply with chemical-specific ARARs, defined by groundwater PRGs, at the point of compliance.

Relative to the CERCLA balancing criteria (**Table 4-3**), this alternative would perform less well for long-term effectiveness and permanence because ?~~47~~ percent of the NAPL mass[7] is estimated to remain at the end of the 100-year O&M period. Additionally, while the adequacy and reliability of the containment measures would be good during the 100-year O&M period, this maintenance would be discontinued after 100 years; therefore, the reliability of these controls would decrease over time. Alternative 2 also would perform less well relative to the TMV reduction through treatment criteria due to the large mass of the NAPL source material that would remain at the end of the 100-year O&M period.

With respect to short-term effectiveness and implementability, Alternative 2 would perform moderately well because risks to the remedial action workers and community are low and the technologies associated with this alternative have been in use at the Site for 20 years. Because this alternative would maintain compliance with chemical-specific ARARs and RAOs only while the hydraulic containment system is in operation during the 100-year O&M timeframe it was rated lower for short-term effectiveness.

The total present worth cost of Alternative 2, based on a 1.4 percent discount rate, is $79~~0~~.8~~6~~ million. Further cost information is shown in **Table 4-3**.

4.2.3 Alternative 3—Excavation, Thermal Desorption, and In Situ Chemical Oxidation

This alternative was screened out in Section 3.3 and not carried forward in the FFS. Therefore, a detailed evaluation of this alternative against the CERCLA criteria was not performed.

4.2.4 Alternative 4—In Situ Solidification/Stabilization

Alternative 4 addresses the NCP requirement to develop an alternative that treats the principal threat posed by the Site but varies in the degree of treatment and the characteristics of the treatment residuals. Under Alternative 4, NAPL present within all remedial action target zones (e.g., entire area enclosed by the TarGOST 10% RE) would be immobilized in situ within a cement – soil solid matrix. The cement concentration used to treat the perimeter of the NAPL source zone would be higher than used to treat the interior portion to create a hardened shell that would have a ~~lower leachability and~~ higher durability to further reduce leaching potential around the perimeter where greater contact with flowing groundwater would occur~~characteristic~~. Passive groundwater discharge treatment is also a component of this alternative that would ~~may~~ be implemented following ~~if post-~~ISS treatment to provide for long-term Upper Aquifer water level control. ~~performance monitoring indicates it is necessary.~~

Evaluation of Alternative 4 against the CERCLA threshold criteria (**Table 4-4**) indicates this alternative would protect current human health by restricting land use and Upper Aquifer and Lower Aquifer groundwater use until RAOs are achieved. Protecting HHE in the future also would be achieved by immobilizing the NAPL, which reduces or eliminates its toxicity and mobility. The hardened shell would provide additional protection for the environment by entombing the NAPL in a leaching resistant matrix. Chemical-specific ARARs in marine surface water would be achieved by immobilizing the NAPL which reduces COC concentrations in FPA soil and groundwater ~~to PRGs~~.

Relative to the CERCLA balancing criteria (**Table 4-4**), this alternative is expected to ~~would~~ perform very well for long-term effectiveness and permanence because ?~~95~~ percent of the NAPL source material would be treated using the ISS technology. The NAPL-soil-cement monolith would have high durability and low leachability, thus minimizing the need for long-term maintenance. Because contaminants are not destroyed or removed, long-term stewardship of the ISS treatment zone would be required. The key

[7] All references to fraction of NAPL mass remaining or mass of NAPL treated are based on the use of naphthalene as a NAPL indicator.

elements of this stewardship include t~~T~~he soil cap and bulkhead common elements to~~would~~ provide protection against erosion that could expose the ISS treatment~~ed~~ zone with institutional controls protecting against inadvertent intrusion into the ISS monolith. This alternative also performs very well for TMV reduction because ISS treatment encapsulates NAPL to form a solid material, with significantly lower toxicity, while reducing contaminant mobility by decreasing the leachability of the NAPL and surface area exposed to leaching processes (e.g. infiltration and groundwater flow). ISS does not decrease the volume of NAPL source material.

Because RAOs would be achieved in an ~~r~~estimated ~~elatively short~~ timeframe of ~~(estimated~~ 12 years~~)~~, with low risk to workers and the community, Alternative 4 would perform moderately ~~very~~ well relative to the short-term effectiveness criteria. ~~This alternative would perform very moderately well for TMV reduction because the volume of NAPL source material toxicity and mobility would not be reduced even though its volume but the mobility and leachability would not be greatly reduced.~~ This alternative also ~~also would~~ performs only moderately well for the implementability criteria due to size (approximately 5 acres) and depth (55 feet) of the ISS treatment zone and the ~~geotechnical~~ auger-drilling challenges associated with ~~potential~~ difficult subsurface ~~drilling~~ conditions (gravel and debris) that may ~~could~~ slow remediation progress.

The total present worth cost of this alternative, based on a discount rate of 1.4 percent, is $90.7~~86.3~~ million. A detailed breakdown of costs is provided in **Table 4-4**.

4.2.5 Alternative 5—Thermal Enhanced Extraction and In Situ Solidification/Stabilization

This alternative addresses the NCP requirement to develop an alternative that removes or destroys contaminants to the maximum extent feasible, eliminating or minimizing, to the degree possible, the need for long-term management. Alternative 5 addresses the principal threat using thermal enhanced extraction to draw NAPL from the subsurface in the Core, North Shallow (LNAPL), and East Shallow (LNAPL) zones~~, and destroying the NAPL in an aboveground thermal oxidation unit~~. Thermal enhanced extraction would be preceded by up to 3 years of enhanced NAPL recovery to shorten the thermal treatment period. EAB would be used as a polishing technology in the thermally treated zones to biodegrade residual NAPL that may remain and in the Other Periphery target zone where NAPL is more disperse and present at lower concentrations. In the North Deep (DNAPL) zone, NAPL would be immobilized using ISS. Passive groundwater treatment also would be a component of this alternative that may be implemented if post-EAB performance monitoring indicates it is necessary.

Evaluating Alternative 5 against the CERCLA threshold criteria (**Table 4-5**) indicates that this alternative would protect current human health by restricting land use and Upper Aquifer and Lower Aquifer groundwater use. Protecting HHE in the future would be achieved by removing NAPL and treating the soil and groundwater to the PRGs that protect HHE. Chemical-specific ARARs in marine surface water would be achieved by reducing COC concentrations in FPA soil and groundwater to PRGs.

Relative to the CERCLA balancing criteria (**Table 4-5**), this alternative would perform very well for long-term effectiveness and permanence and TMV reduction through treatment because ?~~86~~ percent of the NAPL source material would be treated using enhanced NAPL recovery/thermal enhanced extraction/EAB and ?~~12~~ percent using ISS. By removing, immobilizing, and biodegrading NAPL, soil and groundwater PRGs would be achieved, minimizing~~eliminating~~ the need for long-term Site management controls.

Alternative 5 would achieve RAOs within an estimated timeframe of approximately 30 years. During this period, there would be a significant level of daily activity associated with thermal treatment operations. This activity would pose increased risk to the workers and would be visible to the community. Therefore, Alternative 5 would perform only moderately well relative to the short-term effectiveness criteria. This alternative also performs moderately well for implementability due to scale of thermal treatment operations, which requires a significant level of infrastructure and O&M resources and skilled operators.

The total present worth cost of this alternative, based on a discount rate of 1.4 percent, is $141.9~~34.1~~ million. A detailed breakdown of costs is provided in **Table 4-5**.

4.2.6 Alternative 6—Excavation/Thermal Desorption and Thermal Enhanced Extraction

Alternative 6, like Alternative 5, addresses the NCP requirement to develop an alternative that removes or destroys contaminants to the maximum extent feasible, eliminating or minimizing, to the degree possible, the need for long-term management. However, Alternative 6 would utilize excavation and thermal desorption in lieu of thermal enhanced extraction to address the NAPL-contaminated material present in the Upper (e.g., top 20 feet) Core Area. By using sheet pile wall to subdivide the Upper Core Area into three smaller cells, and dewatering each cell to dry the material before excavation, Alternative 6 would be expected to achieve a higher level of treatment in the Upper Core Area than the other alternatives. Unfortunately, the full benefit of the excavation and thermal desorption technology would not be realized under this alternative because most NAPL present in the Core Area lies at depths below 20 feet. As discussed previously in Section 3.3, excavation at depths greater than 20 feet is not technically practicable given Site conditions.

Like Alternative 5, Alternative 6 would use thermal enhanced extraction, preceded by up to 3 years of enhanced NAPL recovery, to draw NAPL from the Lower Core Area, and the North Shallow (LNAPL) and East Shallow (LNAPL) zones; destroying the NAPL in an aboveground thermal oxidation unit. Alternative 6 also would use thermal enhanced extraction to remove NAPL from the North Deep (DNAPL) zone. EAB would be used as a polishing technology, following thermal treatment, to biodegrade residual NAPL that may remain and in the Other Periphery target zone where NAPL is more disperse and present at lower concentrations. Passive groundwater treatment also would be a component of this alternative that may be implemented if post-EAB performance monitoring indicates it is necessary.

Evaluation of Alternative 6 against the CERCLA threshold criteria (**Table 4-6**) indicates this alternative would protect current human health by restricting land use and Upper Aquifer and Lower Aquifer groundwater use. Protecting HHE in the future would be achieved by removing NAPL and treating the soil and groundwater to reduce COC concentrations to PRGs that are protective of HHE. Chemical-specific ARARs in marine surface water would be achieved by reducing COC concentrations in FPA soil and groundwater to PRGs.

Relative to the CERCLA balancing criteria (**Table 4-6**), Alternative 6 performs moderately well for long-term effectiveness and permanence and reduction of TMV because only ?~~14~~ percent of the NAPL source material would be treated using excavation/thermal desorption and ?~~64~~ percent treated using enhanced NAPL recovery and thermal enhanced extraction, respectively. The remaining fraction would be treated using EAB, which may place more dependence on long-term Site controls if EAB treatment rates are lower than estimated. Relative to short-term effectiveness, Alternative 6 would perform moderately well. Although excavation and thermal desorption activities unlikely would pose a risk to the community, the remedial action would create noise, light, and atmospheric discharges that would be visible to the community. Additionally, the thermal desorption equipment would be housed in an enclosed building resulting in a temporary visible impact. Excavation to depths of 20 feet and handling of high temperature steam, vapor, and fluids may also pose increased risk to workers. The time required to achieve RAOs of 28 years would be greater than Alternatives 4 and 5, which justifies a moderately well rating for the short-term effectiveness criteria.

Alternative 6 would perform moderately well for implementability due to its overall technical complexity and the magnitude of resources needed for full implementation.

The total present worth cost of this alternative, based on a discount rate of 1.4 percent, is $197.7 million. A detailed breakdown of costs is provided in **Table 4-5**.

4.2.7 Alternative 7— ISS of Expanded Core Area and Thermal Enhanced Recovery~~Extraction~~

Alternative 7 merges the key technologies of ISS from Alternative 4 and a modified lower temperature thermal enhanced recovery ~~extraction~~ and EAB from Alternative 5 into a standalone option. Under this alternative, ISS would be used to treat the Core Area and the FPA periphery, where ?~~44~~ percent of the NAPL mass occurs. This action would be coupled with thermal enhanced ~~extraction~~ recovery used to treat the East Shallow (LNAPL), North Shallow (LNAPL), and North Deep (DNAPL) zones in an adaptive management approach. If it is shown that the RAOs could be met with only ISS, then the thermal enhanced ~~extraction~~ recovery would not be implemented. Passive groundwater treatment also would be a component of this alternative and would be implemented with ISS.

Thermal enhanced ~~extraction~~ recovery would be preceded by enhanced NAPL recovery and followed by EAB, which would be used as a polishing technology to biodegrade residual NAPL that may remain and in the Other Periphery target zone where NAPL is more disperse and present at lower concentrations.

Evaluation of Alternative 7 against the CERCLA threshold criteria (**Table 4-7**) indicates this alternative would protect current human health by restricting land use and Upper Aquifer and Lower Aquifer groundwater use until RAOs are achieved. Protecting HHE in the future would be achieved by immobilizing NAPL present in the Core Area and the FPA periphery, thereby reducing its toxicity and mobility, and thermally destroying (e.g., off-Site incineration) NAPL recovered from the East Shallow (LNAPL), North Shallow (LNAPL), and North Deep (DNAPL) zones. Chemical-specific ARARs in marine surface water would be achieved by immobilizing and removing NAPL to reduce COC concentrations in FPA soil and groundwater to PRGs.

Relative to the CERCLA balancing criteria (**Table 4-7**), this alternative would performs very well for long-term effectiveness and permanence and TMV reduction through treatment because ?~~37~~ percent of the NAPL source material is treated using ISS and ?~~63~~ percent treated using the enhanced NAPL recovery/thermally enhanced ~~extraction~~recovery/EAB pairing. Within the Core Area, and around the perimeter of the FPA, the NAPL-soil-cement monolith would have durability and low leachability, thus minimizing the need for long-term maintenance. The soil cap would provide protection against surface erosion that could potentially expose the ISS treated zone. Using the adaptive management approach in the remaining target zones, thermal enhanced ~~extraction~~ recovery and thermal destruction of the NAPL, coupled with enhanced NAPL recovery and EAB, would remove the remaining NAPL minimizing or eliminating the need for long-term Site controls if needed to meet the RAOs.

Relative to the CERCLA balancing criteria of short-term effectiveness and implementability, Alternative 7 would perform moderately well for the reasons similar to those described for Alternatives 4 and 5. One notable distinction for Alternative 7 is its ability to achieve RAOs with less reliance on the need for passive groundwater treatment.

Commented [YCK(18]: I am not sure that Alt 7 would achieve lower dissolved phase as compared to Alt 4 or Alt 5, thus less reliance on the passive groundwater treatment.

The total present worth cost of this alternative, based on a 1.4 percent discount rate, is $110.1~~85.2~~ million. A detailed breakdown of costs is provided in **Table 4-7**.

4.3 Comparative Analysis of Remedial Alternatives

This section summarizes the comparative analysis of alternatives, which is designed to assess the advantages and disadvantages of each alternative relative to one another to identify key tradeoffs that should be noted during remedy selection. The comparative evaluation is summarized in **Table 4-8**.

4.3.1 Overall Protection of Human Health and the Environment

All of the alternatives, except Alternative 1 – No Action, would protect current human health by restricting land and groundwater use.

Alternatives 4 through 7 would protect HHE in the future by treating NAPL source material to reduce COC concentrations in soil and groundwater to PRGs. Alternative 2 would protect HHE in the future by reducing or eliminating NAPL and dissolved-phase plume migration, reducing COC concentrations in groundwater, and installing a soil cap across the FPA to provide a barrier against direct contact with contaminated soil.

4.3.2 Compliance with Applicable or Relevant and Appropriate Requirements

Alternatives 4 through 7~~7~~ would achieve Upper Aquifer groundwater PRGs, and chemical-specific ARARs for groundwater discharged to ~~in~~ the intertidal area from the passive discharge/treatment systems, within timeframes that are estimated to be near 8 years for Alternative 7, 10 years for Alternative 5, 12 years for Alternative 4, and 23 years for Alternative 6. Alternative 2 would comply with chemical-specific ARARs while the hydraulic containment system remains in operation, but there is some uncertainty on whether compliance would be maintained if the system is turned off after 100 years. All alternatives except Alternative 1 – No Action would be designed and operated to comply with action and location-specific ARARs.

Commented [YCK(19]: What is the endpoint for these estimated timeframes. From Section 3, Alt 4 – 10 years, Alt 5 – 27 years, Alt 6 – 27 years, and Alt 7 – 34 years.

4.3.3 Long-Term Effectiveness and Permanence

The balancing criterion of long-term effectiveness and permanence considers the following: (1) magnitude of residual risk from untreated waste or treatment residuals remaining at the conclusion of the remedial activities, and the (2) adequacy and reliability of controls such as containment systems and ICs that are necessary to manage treatment residuals and untreated waste. With respect to this criterion, Alternatives 4, 5 and 7 were rated as performing very well, while Alternative 6 was rated as performing moderately well and Alternative 2 less well.

Under Alternative 4, ?~~100~~ percent of the NAPL source material would be treated using the ISS technology, while in Alternatives 5 and 7, ISS would be used to treat ?~~12~~ and ?~~37~~ percent of the NAPL source material, respectively, with the balance of the treatment performed using enhanced NAPL recovery/thermal enhanced extraction/thermal enhanced recovery/EAB. The ISS technology would use vertical augers and jet-grouting equipment to homogenize the NAPL and the cement-based reagent, resulting in a high level of direct contact and overall treatment. Alternatives 5 and 7 would rely on enhanced NAPL extraction and thermal enhanced extraction/recovery to remove the NAPL and EAB to biodegrade any residual NAPL. All three of these technologies would be influenced by subsurface heterogeneities that control transport pathways, which could result in untreated or partially treated zones. Therefore, while Alternatives 4, 5, and 7 were rated as performing very well, Alternative 4 is expected to perform superior followed by Alternative 7 and Alternative 5.

Commented [YCK(20]: Mixing?

Alternative 6 was rated as performing moderately well primarily because there would be greater reliance on EAB following the thermal treatment step. The performance of the EAB technology in this FFS is judged based on its ability to biodegrade naphthalene. The other LPAHs, and high-molecular weight PAHs (HPAHs), do not biodegrade as easily as naphthalene, therefore, other PAHs could persist, even though most of the naphthalene has been degraded. Alternative 2 was rated lowest because it is estimated that ?~~47~~ percent of the NAPL source material would remain untreated at the end of the 100-year O&M timeframe.

4.3.4 Reduction of Toxicity, Mobility, or Volume through Treatment

This balancing criterion assesses the degree to which an alternative employs recycling or treatment to reduce TMV, specifically the following:

- The treatment or recycling processes used and materials they would treat
- The amount of hazardous substances that would be destroyed, treated, or recycled
- The degree of expected reduction in TMV of the waste due to treatment or recycling and the specification of which reduction(s) are occurring
- The degree to which the treatment is irreversible
- The type and quantity of residuals that would remain following treatment, considering the persistence, toxicity, mobility, and propensity to bioaccumulate of such hazardous substances and their constituents
- The degree to which treatment reduces the inherent hazards posed by principal threats at the Site.

With respect to this criterion, Alternatives 5 and 7 were rated as performing very well, while Alternatives 4 and 6 were rated as performing moderately well and Alternative 2 as less well.

Alternatives 5 and 7 were rated higher because thermal enhanced extraction/recovery, in combination with enhanced NAPL recovery and EAB, would result in a high level of NAPL TMV reduction, including thermal destruction of NAPL brought to the surface. While Alternative 6 also includes a major thermal enhanced extraction component because there is more reliance on EAB, it was rated lower than Alternatives 5 and 7. Alternative 4 was also rated lower because, while it would reduce NAPL toxicity and mobility, it would not reduce volume of contaminants contained in NAPL impacted soil. Additionally, although ISS treatment is considered irreversible, there is no performance data to show that the ISS columns can hold up for multigenerational timeframes. Alternative 2 was rated lowest due to the large volume of NAPL that would remain at the end of the 100-year O&M period.

4.3.5 Short-Term Effectiveness

This balancing criterion considers the following:

- Short-term risks that might be posed to the community during implementation of an alternative
- Potential impacts on workers during remedial action and the effectiveness/reliability of protective measures
- Potential environmental impacts of the remedial action and the effectiveness/reliability of mitigation measures during implementation
- Time until protection is achieved

With respect to this criterion, Alternative 4 was rated as performing very well, while Alternatives 2, 5, 6, and 7 were rated as performing moderately well. Alternative 4 was rated higher because the ISS treatment phase would be completed within an approximate 2-year timeframe, whereas under Alternatives 5, 6, and 7 thermal treatment would continue for 8 or more years resulting in long-term visibility to the community, greater risk to workers, and increased potential for environmental impacts. Alternative 2 was rated similar to Alternatives 5, 6, and 7 because, even though O&M continues for 100 years, the level of activity would be significantly lower with less community visibility and risk to workers and the environment.

Alternatives 4, 5, and 7 have remedial action timeframes that range from about 8 to 16 years, while Alternative 6 is estimated to require about 23 years. Alternative 2 is not expected to achieve RAOs within the 100-year O&M timeframe specified in this FFS.

Commented [YCK(21]: Please see estimated timeframes presented in Section 3.

4.3.6 Implementability

This balancing criterion considers the ease or difficulty of implementing an alternative including the following as appropriate:

- Technical feasibility, including technical difficulties and unknowns associated with the construction and operation of a technology, the reliability of the technology, ease of undertaking additional remedial actions, and the ability to monitor the effectiveness of the remedy
- Administrative feasibility, including activities needed to coordinate with other offices and agencies and the ability and time required to obtain any necessary approvals and permits from other agencies (for off-Site actions)
- Availability of services and materials, including the availability of adequate off-Site treatment, storage capacity, and disposal capacity and services; the availability of necessary equipment and specialists, and provisions to ensure any necessary additional resources; the availability of services and materials; and availability of prospective technologies

With respect to this criterion, all alternatives were rated as performing moderately well, with each alternative posing its own unique set of technical challenges. For Alternative 2, the primary implementation challenge would be the overall O&M timeframe of 100 years, which would require replacing extraction wells and portions of the GWTP every 30 years, and long-term staffing, off-Site NAPL disposal, and off-Site GAC media changeout commitments. For Alternative 4, the primary implementation challenge would be the scale of ISS treatment, which would be one of the largest ISS treatment projects to date. Vertical auger mixing to depths of 55 feet and jet injection to depths of approximately 70 feet represent the upper limit for this type of equipment, therefore, treatment rates could be slower than initially estimated. For Alternatives 5, 6, and 7, the overall complexity of enhanced NAPL recovery, thermal enhanced extraction/recovery, and EAB in terms of the number of wells, piping, treatment equipment, and sequencing of each phase across the Site would pose significant implementation challenges.

4.3.7 Cost

As described previously in Table 4-1, the remedial action alternative cost estimates include allowances for the following:

Common elements, including the items listed in Table 3-1
Capital costs, including costs for construction of the key technology components
Annual O&M costs, including costs for operation of the key technology components
~~1.~~ • Periodic costs, including costs for nonrecurring items like equipment replacement

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The total present worth cost (**Table 4-9**) for the alternatives ranges from $86.3 million for Alternative 2 to $185.7 million for Alternative 6. Although cost sensitivity analysis was not specifically performed for this FFS, Alternatives 4 and 5 were evaluated to assess the sensitivity of the present worth cost if capital cost expenditures were limited to a maximum of $15 million per year. These two variations of Alternatives 4 and 5 are shown as Alternative 4a and Alternative 5a, respectively, on **Table 4-8**. Limiting capital costs to $15 million per year increases the present worth cost of Alternative 4 from $86.3 million to $91.4 million while decreasing the cost of Alternative 5 from $134.1 million to $130.8 million.

Remedial action alternative costs were also compared by developing a 25-year cash-flow projection for each alternative; although some alternatives incur costs for more than 25 years (Alternative 2 at 100 years, Alternative 5 at 29 years, Alternative 5a at 32 years, and Alternative 6 at 29 years) and others costs for less than 25 years (Alternative 4 at 12 years, Alternative 4a at 15 years, and Alternative 7 at 22 years). The cost flow projections are presented on **Figure 4-1**.

Commented [YCK(22]: Please see estimated timeframes presented in Section 3.

SECTION 5

5 Recommended Alternative

To be provided.~~Due to a shorter estimated timeframe to achieve RAOs (see Exhibit ES-2), and a lower level of long-term Site management, Alternative 4 was initially identified during stakeholder discussions as the recommended alternative. Further, EPA and Ecology discussions are planned, and a presentation to the National Remedy Review Board may result in a different recommended alternative or identification of new technology combinations and new alternatives. Selection of the final alternative will occur in a CERCLA decision document following completion of the public participation process.~~

SECTION 6

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Figures

Appendix A
Soil and Groundwater Operable Unit Applicable or Relevant and Appropriate Requirements

Appendix B
Remedial Action Alternative Drawings

Appendix C

~~Common Element and~~ Remedial Action Alternative Cost Estimates

~~Appendix D~~
~~Remedial Action Alternative~~
~~Timeframe Projections~~

~~APPENDIX D~~

~~Remedial Action Alternative Timeframe Projections~~

~~*Note: This appendix will be submitted with the next submittal.*~~

Appendix D~~E~~
Wyckoff NAPL Composition